TVS-CV-82-109

Test and Demonstration of Double and Triple Trailer Combinations

W.R.J. Mercer
Research Officer

J.R. Billing
Research Officer

Transport and Vehicle Systems

M.E. Wolkowicz
Senior Research Technician
Experimental Demonstration and Testing

Published by:
The Transportation Technology and Energy Division
Ontario Ministry of Transportation and Communications
Hon. James W. Snow, Minister
H.F. Gilbert, Deputy Minister

Published without prejudice
as to the application of the findings.
Crown copyright reserved; however, this
document may be reproduced for non commercial
purposes with attribution to the Ministry

For additional copies write:
The Editor
Research and Development Branch
Ministry of Transportation and Communications
1201 Wilson Avenue
Downsview, Ontario
M3M 1J8

August 1982

ABSTRACT

Industry is currently proposing that longer trucks be permitted on Ontario's highways to enhance productivity. In support of this, three overlength trucks, a Triple, a Twin 45 and a Double Car Carrier, all 30 to 35 m (100 to 115 ft) long, were made available for testing by the Ministry, and for demonstration to the Ontario Commission on Truck Safety.

The objectives of the testing were to validate findings of others regarding the characteristics of such vehicles, and to become as familiar as possible with them. The limited test period did not permit either a comprehensive technical evaluation of all possible longer trucks, nor did it address issues of a social, economic, public perception or regulatory nature. Low speed offtracking, brake system operation, response to an emergency evasive manoeuvre, and splash and spray generation characteristics of all vehicles were evaluated.

The overlength vehicles were found to require more space to manoeuvre than the standard tractor-trailer. Brake system performance for longer trucks made up of standard trailers was less than ideal. The evasive manoeuvre demonstrated possible modes of instability of such vehicles. Splash and spray was shown to be reduced by suitably equipping the vehicles.

The demonstration was conducted on Highway 401. This report observes that the longer trucks were not atypical of other trucks present on the highway during the demonstration.

TABLE OF CONTENTS

	PAGE
ABSTRACT	i
1/ INTRODUCTION	1
2/ DESCRIPTION OF VEHICLES	5
3/ TEST AND DEMONSTRATION PROGRAM	13
3.1/ Test and Demonstration Philosophy	13
3.2/ Test Equipment	14
3.2.1/ Test Sites	14
3.2.2/ MTC Test Tractor	14
3.2.3/ Test Instrumentation	17
3.3/ Test Manoeuvres and Procedures	17
3.3.1/ Lateral Acceleration Amplification	17
3.3.2/ Air Brake Timing	20
3.3.3/ Stopping Distance	21
3.4/ Demonstration Manoeuvres	21
3.4.1/ Response to Lane Change and Passing	21
3.4.2/ Interaction With Traffic	21
3.4.3/ Splash and Spray	22
3.4.4/ Offtracking	22
4/ TEST AND DEMONSTRATION RESULTS	25
4.1/ Lateral Acceleration Amplification	25
4.2/ Brake Timing	32
4.3/ Stopping Distance	34
4.4/ Response to Lane Change	42
4.5/ Interaction With Other Traffic	46
4.6/ Splash and Spray	47
4.7/ Offtracking	51
4.7.1/ Constant Radius Test	51
4.7.2/ Swept Path Test	51

PAGE

5/ DISCUSSION 68
5.1/ Lateral Acceleration and Response to Lane Change 68
5.2/ Brake Timing 69
5.3/ Stopping Distance 70
5.4/ Interaction with Traffic 70
5.5/ Splash and Spray 71
5.6/ Offtracking 72

6/ CONCLUSIONS 73

ACKNOWLEDGEMENTS 74

REFERENCES 75

1/ INTRODUCTION

Representations have been made to MTC from time to time by motor carriers seeking permission to introduce truck combinations longer than the 21 m (68.9 ft) current Ontario maximum overall length. Combinations of overall length up to 33.5 m (100 ft) are widely used in the western U.S.A. Canadian Freightways started operation with triple-trailer trains between Calgary and Edmonton in 1969, and has had an enviable safety record since. The greater productivity of these long combinations is illustrated by fuel savings of 30% to 45% compared with the typical 18 m (60 ft) tractor/trailer [1]. Reference 1 also thoroughly documents other aspects of the performance and operation of these trucks.

The Ontario Parliamentary Select Committee on Highway Safety, which reported in 1977, recommended that the then-current maximum overall length of 19.8 m (65 ft) not be increased [2]. The basis of this recommendation was that neither the industry nor MTC had made a compelling case for an increase; therefore, concerns made known by the public were given precedence. The subsequent minor length increase came from conversion to the metric system in 1978.

In October, 1981, the Ontario Commission on Truck Safety was announced by the Hon. James Snow, Minister of Transportation and Communications, with Dr. Robert J. Uffen of Queen's University appointed as Commissioner. The terms of reference of the Commission included specific investigation of the following:

1/ driver training, education, licensing, medical standards, and management;

2/ standards and specifications for safety, truck inspection, and truck maintenance;

3/ rules of the road; and

4/ public and industry perceptions and expectations.

The Commission held public hearings and received briefs and other submissions. One of these, under the sponsorship of the Ontario Trucking Association (OTA), made a strong case for consideration of the productivity benefits of longer trucks. In support of this, three trucking companies offered to provide typical vehicles to the Commission for demonstration and testing. The offer was accepted, and arrangements were made for demonstration and test of the following:

1/ a twin-trailer Car Carrier in B-train configuration, having unloaded and loaded overall lengths of 33.5 and 35 m (110 and 115 ft), respectively;

2/ a Turnpike Double, or Twin 45, a tractor with two 13.7 m (45 ft) semitrailers, with an overall length of 33.1 m (108.7 ft); and

3/ a Triple, a tractor with an 8.2 m (27 ft) semi-trailer and two similar full trailers, with an overall length of 30.1 m (100.5 ft).

The demonstration was arranged around a return trip on Highway 401 between Oshawa and Belleville, under an overlength special permit. This allowed the Commissioner to see these trucks in normal intercity operation both on-board as a passenger and as an observer from an automobile. Demonstrations of other truck operations were also arranged on this trip. The objective of the demonstration was to permit the Commissioner to assess the relationship between the longer trucks and traffic currently using the highway.

The testing was arranged at the MTC Commercial Vehicle Test and Research Facility at Huron Park. Tests of turning, braking, handling, dynamic characteristics, and splash and spray were conducted. The objective of the test was two-fold. First, the results would give the Commission a basis for evaluating the published findings of others. Second, the opportunity to work with these trucks would enhance the understanding of the dynamics and handling of such trucks within MTC, and provide groundwork for future research.

This report presents outlines and findings of specific tests of three overlength trucks, a double Car Carrier, a Twin 45, and a Triple. It also presents some subjective observations from the demonstration run of these trucks made for the Ontario Commission on Truck Safety along Highway 401 between Oshawa and Belleville. The report is limited in scope due to the abbreviated test period and is not an assessment of the suitability of such trucks for regular operation in Ontario. Indeed, the owners of two of the trucks indicated that if operation of such trucks would be approved, they would operate with different configurations and systems than those of the vehicles they provided for this work.

2/ DESCRIPTION OF VEHICLES

The Car Carrier as supplied for the test and demonstration is described in Figures 1 and 2. It is a special vehicle, engineered to be operated as a unit.

The Twin 45 as supplied for the test and demonstration is described in Figures 3 and 4. It was made up from stock equipment operated by the owner.

The Triple as supplied for the test and demonstration is described in Figures 5 and 6. It was also made up from stock equipment operated by the owner, and was not necessarily typical of all triples.

The reference vehicle is comprised of the MTC tractor, described in Section 3.2.2, and a trailer from the Twin 45. These are shown in Figures 7 and 3, and Table 1.

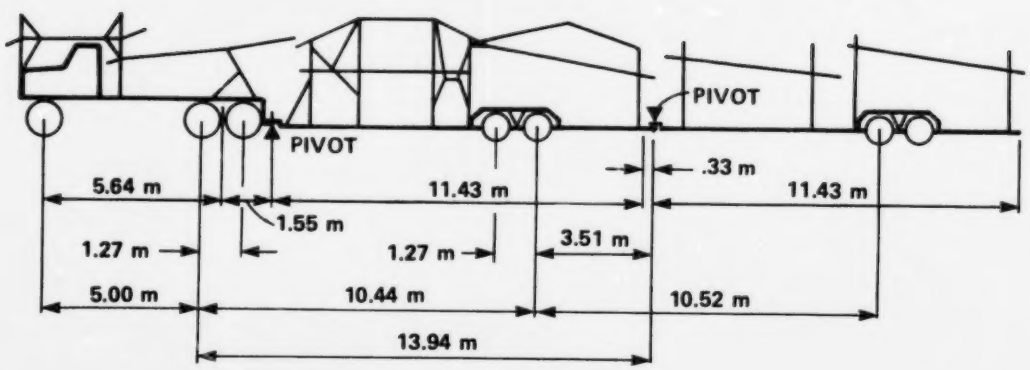


Figure 1/ Car Carrier

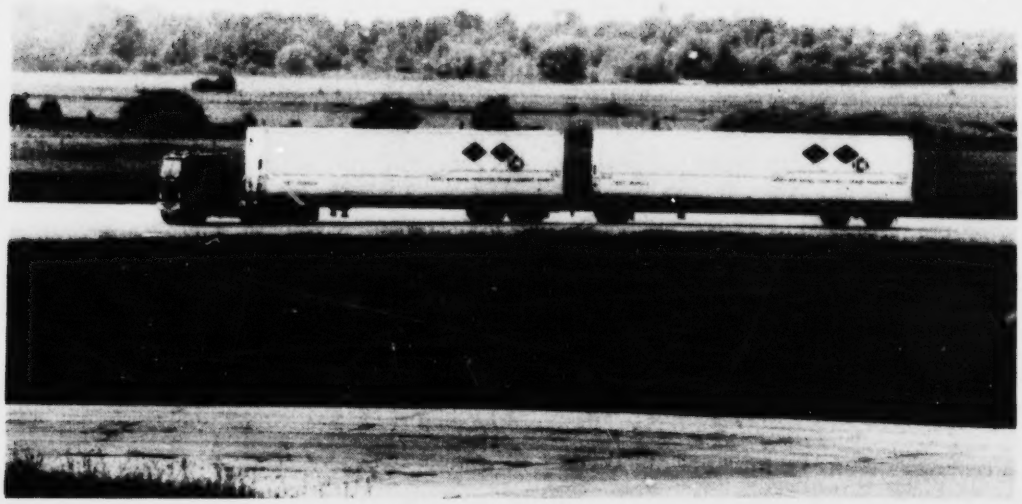
TRUCK DATA

Total Mass as Tested (Empty):		30 130 kg
Demonstration Mass:		52 150 kg
Tractor:	Make:	Chevrolet Bruin
	Model:	6V92T2
	Tire Type:	Front/Michelin 275/80R22.5
		Rear/Goodyear G167-11R22.1
	Tire Pressure:	517 kPa (75 psi)
	Number of Axles:	3
Trailer(s):	Quantity:	2
	Make:	Bankhead
	Model:	S9L
	Tire Type:	Goodyear 11R7.5 HC
	Tire Pressure:	517 kPa (75 psi)
	Number of Axles:	2

Axle Loads (kg):

Axle	Demonstration	Test (Empty)
1	5 850	4 970
2+3	12 620	7 220
4+5	19 470	10 430
6+7	14 210	7 510
Total	52 150	30 130

Figure 2/ Car Carrier Data



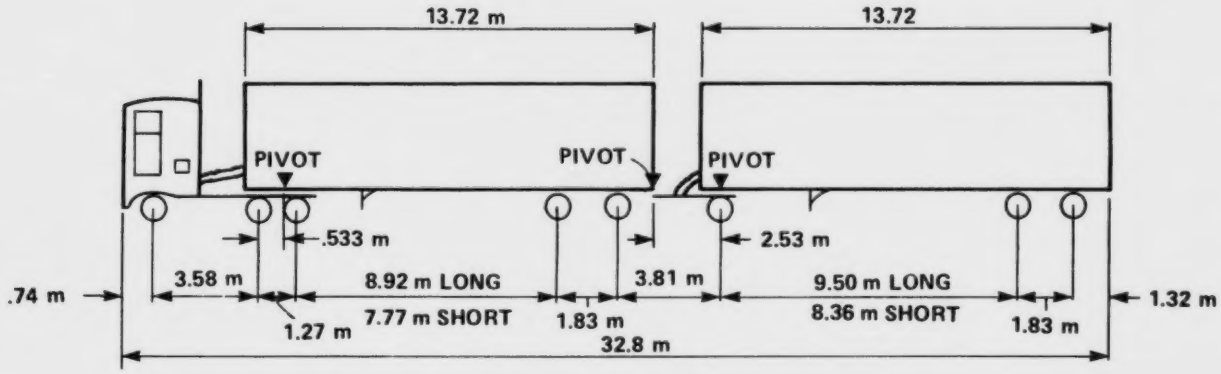


Figure 3/ Twin 45

TRUCK DATA

Total Mass as Tested (Empty):		22 418 kg
Demonstration Mass:		64 730 kg
Tractor:	Make:	GMC
	Model:	Astro
	Tire Type:	Michelin Radial 11R-24.5
	Tire Pressure:	517 kPa (75 psi)
	Number of Axles:	3
Trailer(s):	Quantity:	2
	Make:	Trailmobile
	Model:	0267032 (Van 80)
	Tire Type:	Uniroyal 11-22.5, 12 ply
	Tire Pressure:	517 kPa (75 psi)
	Number of Axles:	2
Dolly:	Quantity:	1
	Make:	Trailmobile
	Tire Type:	Uniroyal 11-22.5, 12 ply
	Tire Pressure:	517 kPa (75 psi)

Axle Loads (kg):

Axle	Demonstration	Test (Empty)
1	5 360	4 064
2+3	14 110	5 536
4+5	18 310	4 755
6	9 810	3 518
7+8	17 140	4 546
Total	64 730	22 418

Figure 4/ Twin 45 Data

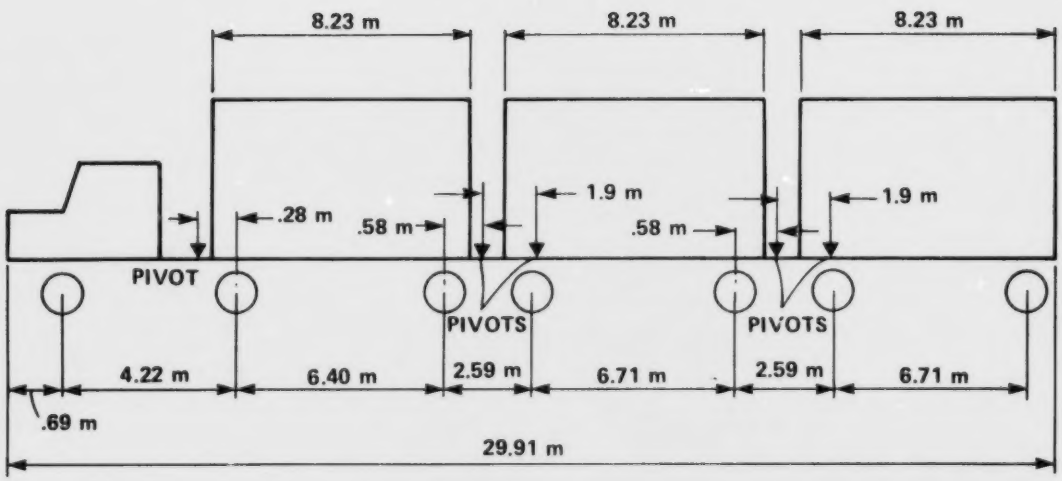


Figure 5/ Triple

TRUCK DATA

Total Mass as Tested (Empty):		21 392 kg
Demonstration Mass:		41 610 kg
Tractor:	Make:	Ford
	Model:	9000
	Tire Type:	Michelin 11R24.5 X-MS
	Tire Pressure:	517 kPa (75 psi)
	Number of Axles:	2
Trailer(s):	Quantity:	3
	Make:	Fruehauf
	Model:	FGX-F2-27-102
	Tire Type:	Goodyear R11-22.5
	Tire Pressure:	517 kPa (75 psi)
	Number of Axles:	1
Dolly:	Quantity:	2
	Make:	Fruehauf DXN
	Tire Type:	Goodyear R11-22.5
	Tire Pressure:	517 kPa (75 psi)

Axle Loads (kg):

Axle	Demonstration		Test (Empty)
1	4 430	Tractor	7 119
2	9 460		
3	5 550	Trailer	3 909
4	5 930	(3 of each)	
5	5 130		
6	5 990	Dolly	1 273
7	5 120	(2 of each)	
Total	41 610		21 392

Figure 6/ Triple Data

Table 1/ MTC Tractor Specifications

MODEL:	White Freightliner with tandem drive axles, 4.5 m wheelbase, cab over engine (COE), sleeper type		
ENGINE:	V-12 Detroit Diesel, 465 Hp @ 2100 rpm		
STEERING:	37.6:1 Constant ratio/power assist		
AXLES:		FRONT	REAR
	CAPACITY	8 165 kg	19 960 kg
	SUSPENSION	Leaf spring	Hendrickson RTE 440 (1.83 m spread walking beam)
	STATIC LOAD	4 760 kg	5 630 kg
TIRES:	TYPE	Firestone Transport -1 Bias Ribbed	
	SIZE	11.00 - 22.5	
WHEELBASE:		4.5 m	
MASS CTR.		2.29 m aft of front axle 0.91 m above ground	

Figure 7/ MTC Tractor

3/ TEST AND DEMONSTRATION PROGRAM

3.1/ Test and Demonstration Philosophy

The tests and demonstration were intended to expose the basic performance characteristics of the trucks relative to normal highway operation. They encompassed both qualitative and quantitative parameters, and provided a comprehensive operational scenario with visual evidence and data on performance levels.

Evaluation by demonstration was conducted on Highway 401, and the Centralia Test Facility. Demonstrations involved highway manoeuvres in both overtaking and being overtaken by various vehicles including similar tractor/trailer combinations, splash and spray characteristics, and manoeuvring in confined spaces such as ramps and intersections.

The quantitative portion of the test plan was designed to gather data on dynamic and mechanical characteristics of the combinations for comparison to previous tests [1,3] and between trucks. This was done to obtain comparative test experience, examine methodology, and highlight characteristics of the combinations tested that may reveal peculiarities. A test was designed to indicate vehicle dynamic sensitivity to the rapid steer manoeuvres that can result in dynamic instability and, hence, loss of control. Other tests included braking to yield stopping distances, and an examination of brake application and release timing to determine brake programming.

This work was oriented to reflect the practical operational characteristics of the overlength vehicles by subjecting them to selected controlled tests which were designed to generate summary effects and expose characteristics that may not normally surface during discrete system analysis due to coupling effects within the vehicle.

3.2/ Test Equipment

3.2.1/ Test Sites

The sites used in the generation of data for this report were as follows:

1/ Highway 401 west- and eastbound between Oshawa and Belleville was used for observation of:

- response to lane change;
- response to traffic;
- passing and being passed by traffic; and
- splash and spray effects.

The composition and texture of Highway 401 is such that it bears no relevance to the subjective nature of the tests carried out and will not be detailed in this report.

2/ MTC Test Facility at Huron Park, Centralia was used to examine:

- splash and spray characteristics;
- lateral acceleration amplification;
- air brake timing;
- stopping distance; and
- offtracking.

The MTC Test Facility, shown in Figure 8, is a former Air Force training base at Centralia, Ontario, now known as Huron Industrial Park. The north/south runway is 1000 m long and 50 m wide, and a 200 m section of it was resurfaced to provide a smooth, low-friction surface for manoeuvres. A curved roadway with a radius of 87 m provides a constant radius turn entry to the test area. The test area can be kept wet by sprinklers mounted on both sides. The skidpad is an asphalt concrete with a sand mix of very fine angular aggregate.

3.2.2/ MTC Test Tractor

The MTC test vehicle is a White Freightliner COE Tandem-Axle Tractor and is described in Table 1. It is instrumented to measure test variables as described in Table 2.

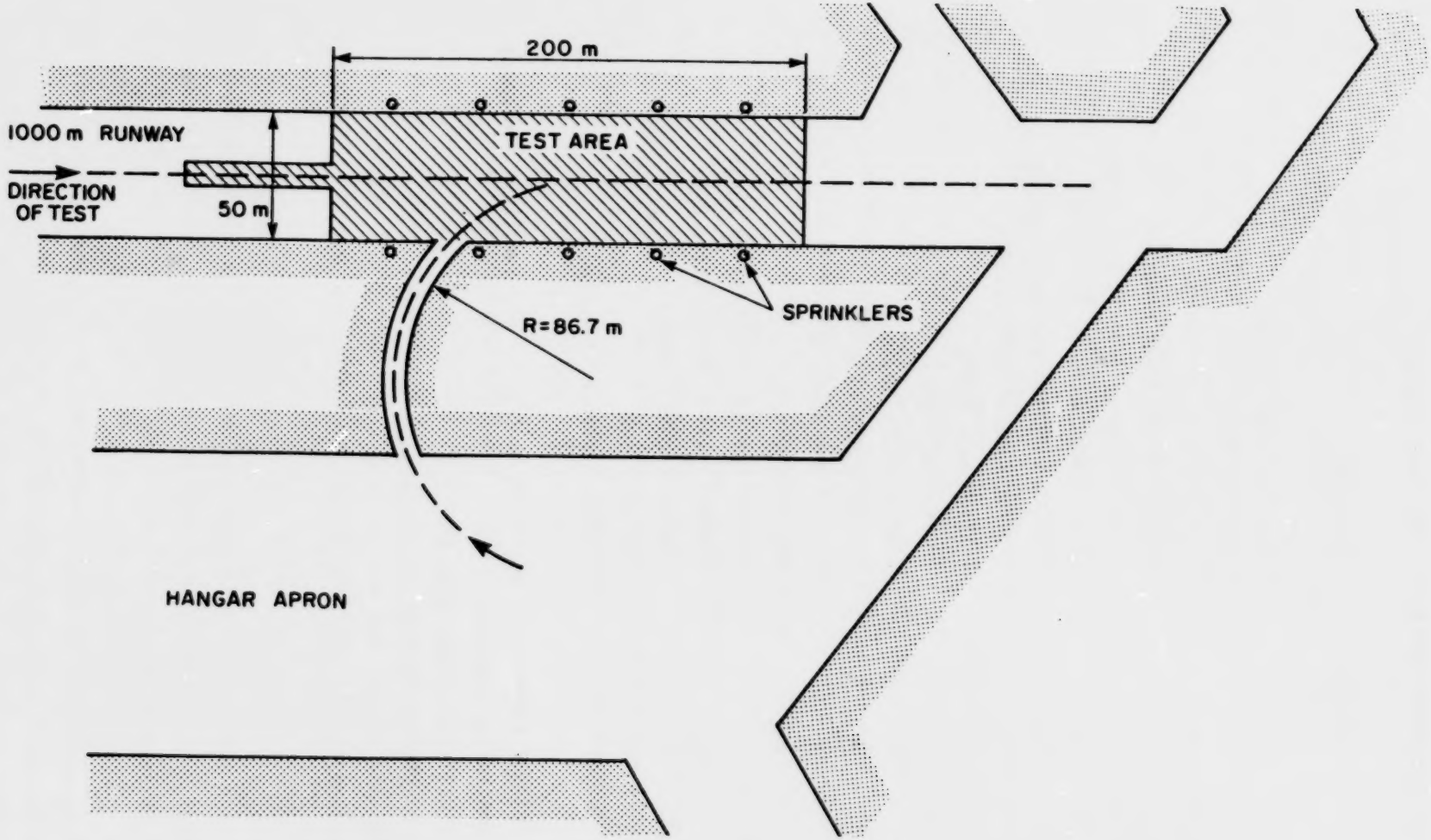


Figure 8/ MTC Test Site

Table 2/ Monitored Variables, MTC Test Tractor

NO.	SYMBOL	PARAMETER
1	δ_s	Steering Wheel Angle
2	$\dot{\delta}_s$	Steering Wheel Rate
3	$Bo/_o$	Foot Brake on/off Switch
4	PBT	Treadle Valve Brake Pressure
5 to 9	P_{Ail}	Brake Pressure, axle i, left side
12 to 17	W_{Ail}	Wheel speed, axle i, left side
18	A_{xt}	Tractor Longitudinal Acceleration
19	A_{yt}	Tractor Lateral Acceleration
20	ϕ	Tractor Roll Angle
21	$\dot{\phi}$	Tractor Roll Rate
22	θ	Tractor Pitch Angle
23	$\dot{\theta}$	Tractor Pitch Rate
24	ψ	Tractor Yaw Angle
25	$\dot{\psi}$	Tractor Yaw Rate
28	γ_1	Tractor Trailer Articulation Angle
29	$\dot{\gamma}_2$	Tractor Trailer Articulation Rate
30	s	Tractor Sideslip Angle
31	V	Tractor Speed
32	S	Tractor Distance Travelled

NOTE: Omitted numbers are dedicated to trailer and auxiliary equipment monitoring channels.
-Trailer(s) brake pressure
-Trailer(s) lateral acceleration

3.2.3/ Test Instrumentation

The vehicles were instrumented to measure driver steering input and the resulting dynamic responses. A number of transducers were located on the tractor(s) and trailer(s) to measure variables of interest. Selected variables were chosen as primary, while the balance were used where necessary to verify primary measurements. Testing configurations are outlined in Table 3 and variables are outlined in Table 2.

3.3/ Test Manoeuvres and Procedures

3.3.1/ Lateral Acceleration Amplification

An articulated vehicle having more than one unit is prone to high lateral forces at the rear unit as a result of rapid driver steering inputs. This can be likened to a whip action, where a relatively small snapping action at the handle produces exaggerated effects at the tail. In the case of a tractor with double or triple trailers, a rapid driver steering input such as might occur in an emergency manoeuvre can be magnified between the tractor and the rearmost trailer of the train. Since no forces can be transmitted forward through the articulation joints, the driver has no sense of this happening. Such a condition can yield forces on the rear trailers in excess of those available to maintain stability. This may cause trailer swing or dolly jackknife on a low-friction surface, or rollover on a high-friction surface.

This is further complicated because a time lag exists between the driver's action and the trailer's reaction. The effect can compound the forces when a driver attempts a corrective action by referring to his "seat of the pants" feeling. This time lag and the lateral acceleration wave progression and magnitude were investigated for each segment of the train.

The test measured the lateral acceleration of the tractor and trailers produced as a result of a standard driver steering manoeuvre. These accelerations are indicative of the actual lateral forces generated.

The trucks were configured as specified in Table 3, and driven up to a speed of 50, 65 or 80 km/h. The driver then performed a vigorous double-lane change manoeuvre as shown in Figure 9. This was done by an

Table 3/ Vehicle Configuration and Test Locations

TEST/DEMO	VEHICLES		LOCATION		GROSS
	TRACTOR	TRAILERS*	401	MTC	WEIGHT(kg)
Lateral Acceleration	MCL	MCL (2)		X	30130
	MTC	INTERCITY (3)		X	21392
	MTC	ICL (2)		X	22418
Brake Timing	MCL	MCL (2)		X	30130
	MTC	INTERCITY (3)		X	21392
	MTC	ICL (2)		X	22418
Stopping Distance and Splash and Spray	MCL	MCL (2)		X	30130
	INTERCITY	INTERCITY (3)		X	21392
	ICL	ICL (2)		X	22418
Lane Change Response and Traffic Response	MCL	MCL (2)	X		52150
	INTERCITY	INTERCITY (3)	X		41610
	ICL	ICL (2)	X		64730
Offtracking	MCL	MCL (2)		X	30130
	INTERCITY	INTERCITY (3)		X	21392
	ICL	ICL (2)		X	22418
	MTC	ICL (1)		X	-

* Trailers are broken down as follows:

a/ MCL -- Car Carrier as described in Figures 1 and 2

b/ INTERCITY -- Triple 8.23 m (27 ft) trailers as described in Figures 5 and 6

c/ ICL -- Twin 13.72 m (45 ft) trailers as described in Figures 3 and 4

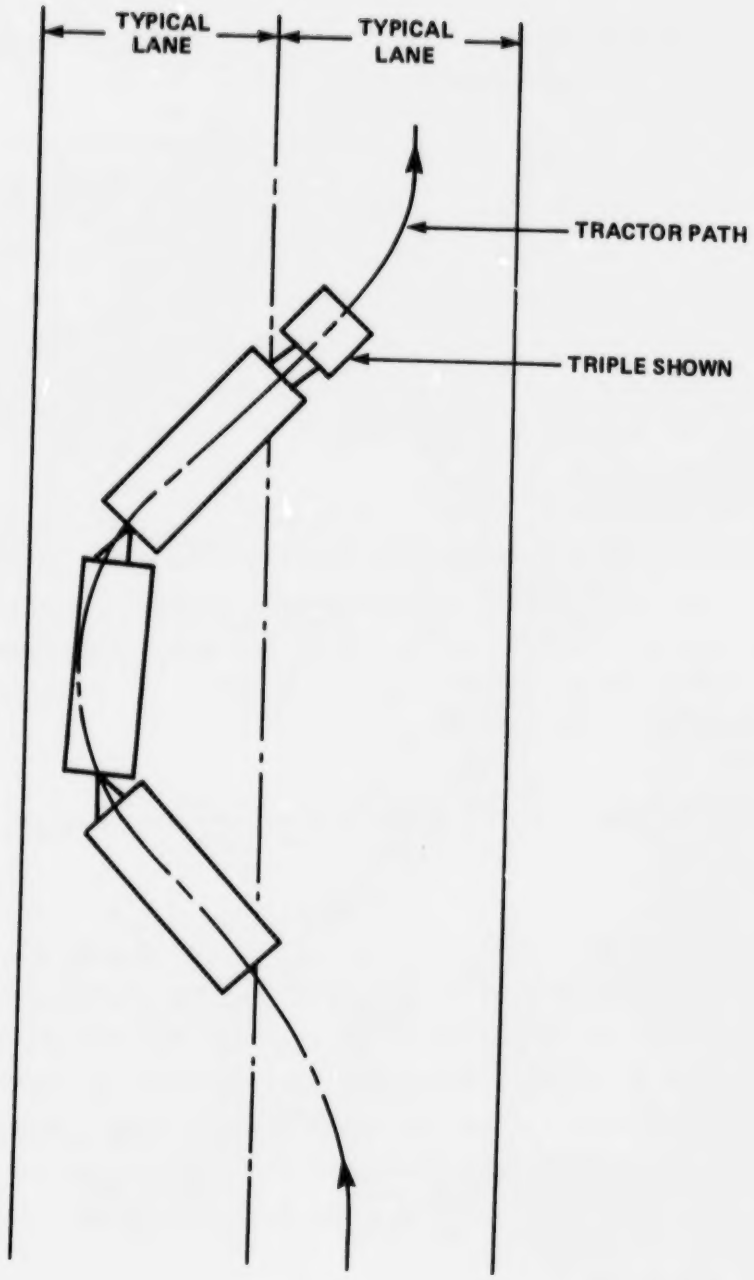


Figure 9/ Double Lane Change Manoeuvre

S-shaped steering input, which moved the truck out of lane and back into lane. The steering input was made of various movements, and was chosen so that lateral accelerations were well below those likely to cause rollover. Lateral acceleration of each trailer was monitored throughout the manoeuvre to ensure safety.

3.3.2/ Air Brake Timing

Vehicle train stability when braking is related to the sequencing of application of the brakes on the various axles. If the axles of a train are braked from the rear forwards, tension develops in the articulated joints, which promotes controlled straight line-stopping by inhibiting destabilizing lateral forces. A vehicle that is progressively braked from the rear to the front will normally exercise directional stability during braking.

To maintain a stable scenario in a braking-and-release situation, the brakes should also release in a programmed sequence, beginning at the front of the vehicle and progressing to the rear. This restores directional control to the driver, commencing initially at the tractor and moving through to the trailer(s).

This test measures brake application times on various axles of the train.

In order to supply a uniformly high-quality air supply, the MTC tractor was used where possible as an air source for the timing test. A brake pressure sensor was installed on the rearmost axle set of each trailer and connected to tractor instrumentation. Tractor instrumentation monitored brake pedal actuation, brake treadle valve output pressure, tractor brake pressure, and trailer brake pressures against time with the vehicle stopped. At least three brake applications were performed.

3.3.3/ Stopping Distance

The distance that a vehicle requires to come to a complete stop from speed, perhaps more so than any other vehicle effect, is a culmination of many variables working as a system to slow the vehicle.

Each train was tested with its own tractor to ensure a representative overall vehicle performance profile. To eliminate driver effects as much as possible, all tests were held on the same test course using the same driver.

Each vehicle was driven at a speed of 32 km/h and the brakes were applied. The distance between the brake application point and the final stopping point was measured.

3.4/ Demonstration Manoeuvres

3.4.1/ Response to Lane Change and Passing

This manoeuvre demonstrated the ability of a train to negotiate a lane change and pass other vehicles. It permitted assessment of such a manoeuvre in the normal traffic flow. The objective was to examine train weaving, transient effects, and responses both from the standpoint of the overtaking vehicle and the vehicle being overtaken.

Although neither calculation nor measurement was employed, the assessment included many factors inherent in vehicle dynamics, such as transient slip stream affects, buffetting, train weaving and particulate generation.

The trains were observed while passing from an automobile operating in the right lane at approximately 80 km/h. The truck speed was approximately 100 km/h. Observations were noted and sequences were videotaped.

3.4.2/ Interaction with Traffic

In this exercise, the effect of the train on highway traffic, and vice versa, from the standpoint of passing, lane changing, exiting and entering the highway, slowing for obstructions, pulling off to the shoulder, and other effects of normal day-to-day highway operation was observed. Effects monitored were train weaving, automobile drivers' responses,

aerodynamic responses, and any other response worthy of note during routine vehicle operation. The trains were observed as they operated in traffic, and specific situations were recorded on video.

3.4.3/ Splash and Spray

A vehicle operating on a wet surface generates splash and spray both from the wheel interaction with the ground and from aerodynamic flow around the vehicle. In certain atmospheric and ground conditions the spray from trucks can obscure the vision of motorists either passing or being passed by a larger vehicle. This demonstration served to evaluate the splash and spray generated by a passing train and compared the spray patterns of the test vehicles in terms of relative density, duration, nature and spread.

The test area was wetted by the sprinkler system, and each truck was driven at 75 km/h through the wetted area. The spray pattern was observed from overhead and road level, and was recorded on video.

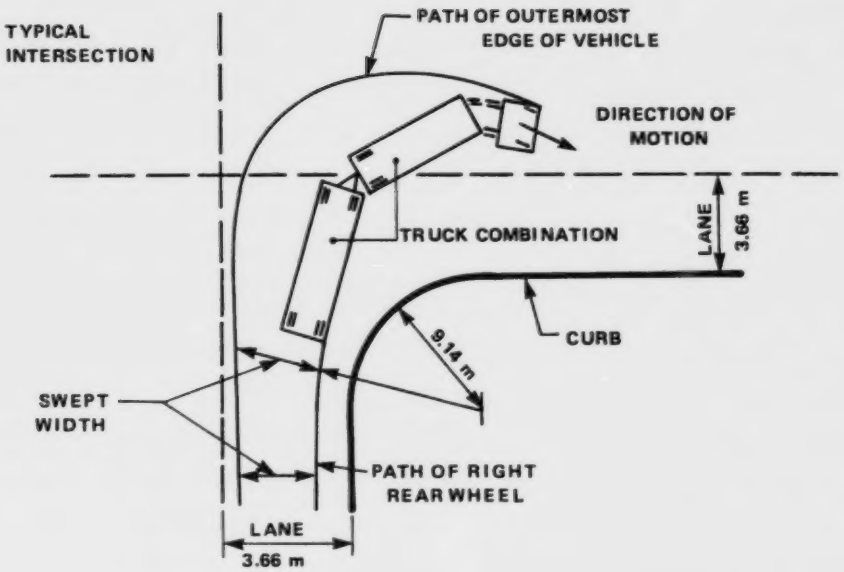
3.4.4/ Offtracking

Offtracking is the deviation of trailing axles of a vehicle train from the path of the tractor steering axle during turning at slow speed. This is seen when a tractor/semitrailer negotiates a turn at an intersection, where the tractor must swing out and proceed into the intersection prior to steering, to avoid cutting the corner with the trailer rear wheels.

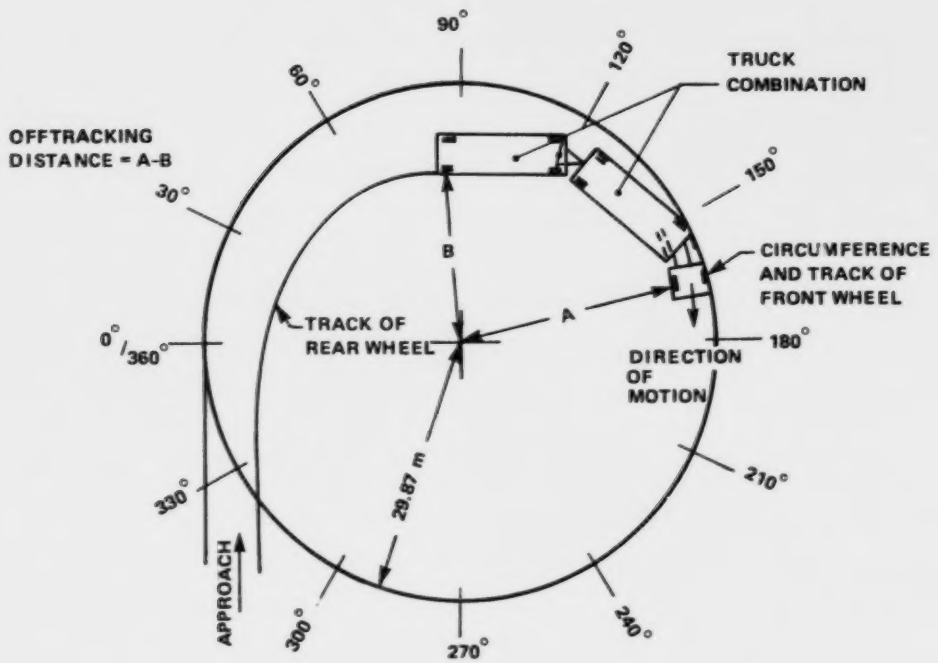
To demonstrate offtracking two basic tests were conducted:

- swept area of a 90° right hand turn, and
- constant radius turn.

The swept area method envelopes the path of the train as it travels around a turn, Figure 10a. The 9.14 m (30 ft) curve radius was selected from MTC highway design standards. It is demonstrated by marking the ground with cones at the front left corner of the tractor and the rear right corner of the rearmost trailer as it negotiates the turn. This basically indicates the path width necessary to operate that particular vehicle through the turn. The constant radius test is a measurement taken when driving the truck at low speed in a circle. The radius at



(a) Swept Area Offtracking Layout



(b) Constant Radius Offtracking Layout

Figure 10/ Offtracking Layouts

which the tractor travels the circle, minus the radius at which the rear axle travels it, is the offtracking distance, Figure 10b. Measurements are taken at the rear axle as the tractor continues around the circle and terminate when the measurements stabilize, thus indicating the maximum offtracking.

4/ RESULTS

4.1/ Lateral Acceleration Amplification

Each train was operating at speeds of about 50, 65 and 80 km/h, when a steer input was made to effect an evasive manoeuvre, a lane change with immediate return to the original lane thus generating a 0.35 to 0.55 g lateral acceleration at the tractor. The lateral acceleration in the tractor and each trailer of the train was measured and recorded.

Plots of the measurements are shown in Figures 11, 12 and 13. The dynamic motion is seen to be transmitted from the tractor to the trailers of the train. The lateral acceleration amplification is the ratio of peak lateral acceleration at a trailer to peak lateral acceleration at the tractor, and the lag time is the time between peak acceleration at the tractor and peak acceleration at the trailer. The lag times and lateral acceleration amplifications are shown in Figures 14, 15 and 16.

Both the Triple and the Twin 45 had amplifications less than 1.0 at the initial testing speeds, so the trailers had lower accelerations at those speeds than the tractor. The Car Carrier had an amplification greater than 1.0 at all speeds, so higher lateral accelerations were experienced at the trailers than the tractor. As the distance of a trailer from the tractor increased, the slope of the amplification/speed curve also increased. All vehicles exhibited this phenomenon.

The lag times in all cases appeared to remain relatively constant with speed, except for the Twin 45, which showed some convergence between its trailers at higher speeds.

At the highest speeds the Triple rolled into the spring lash range and occasionally lifted the wheels of the rear trailer. The higher center of gravity of the van type trailers implied that the predominant instability mode is that of rollover.

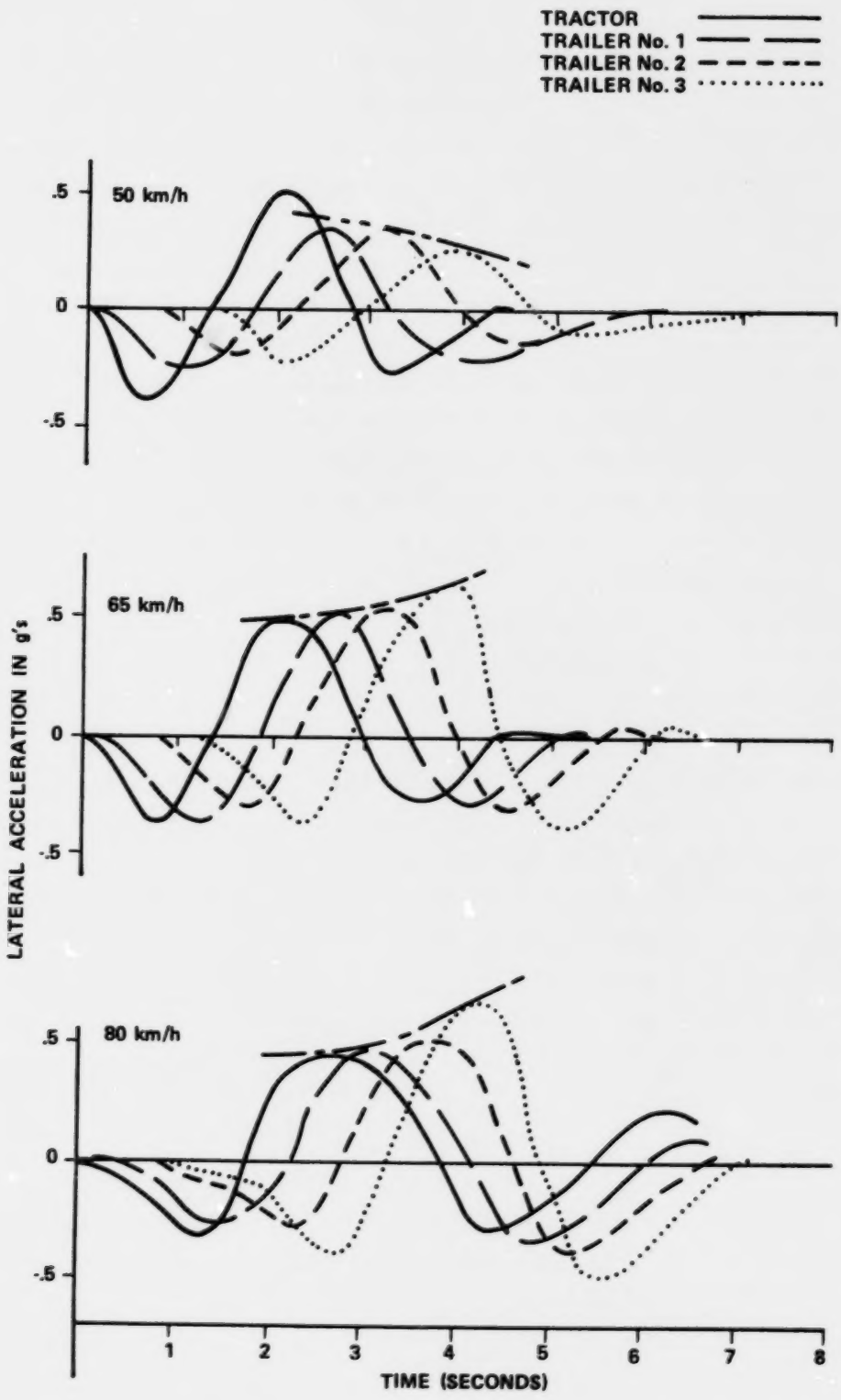


Figure 11/ Typical Plot of Lateral Acceleration vs Time for Triple

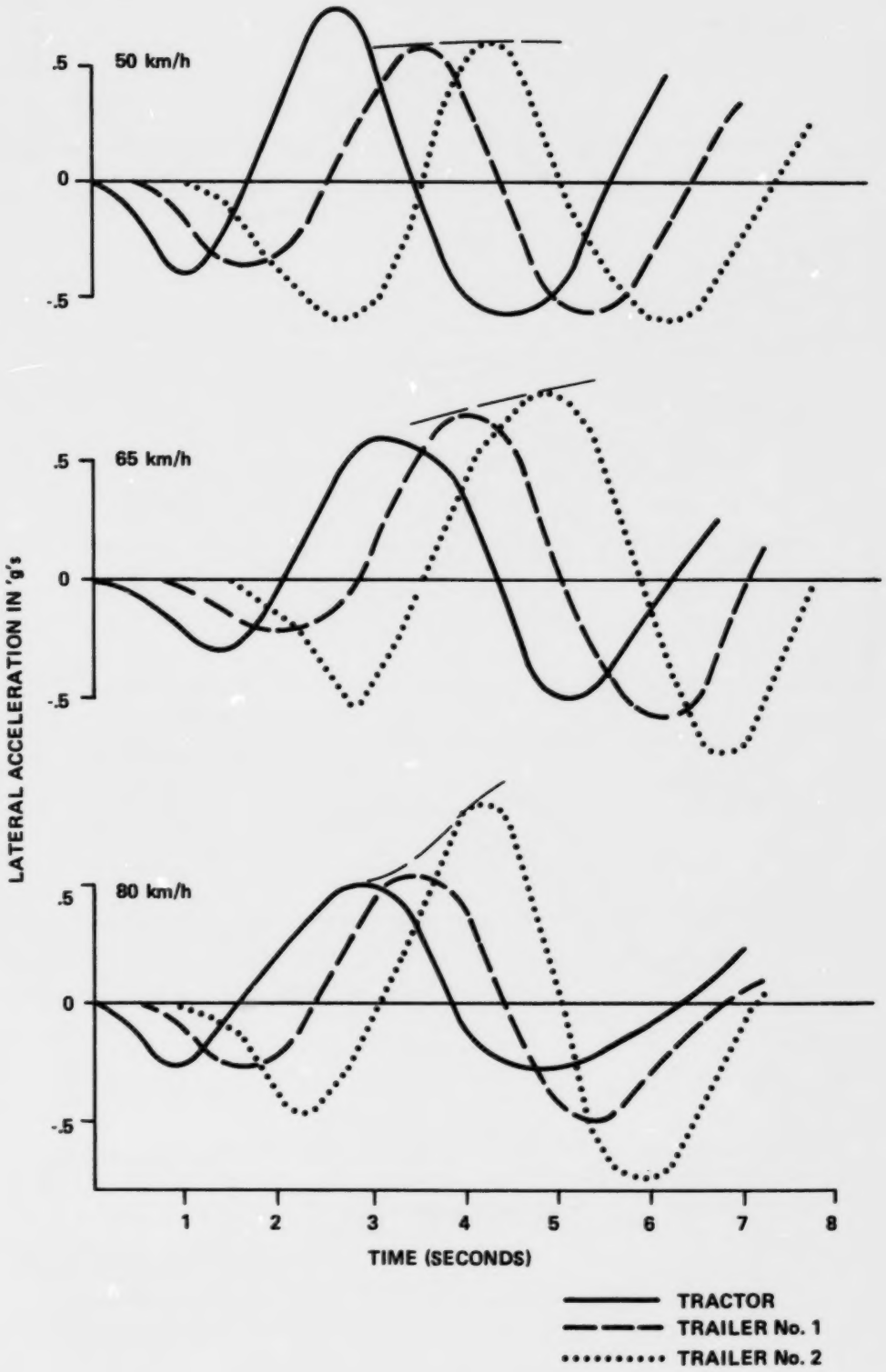


Figure 12/ Typical Plot of Lateral Acceleration vs Time For Car Carrier

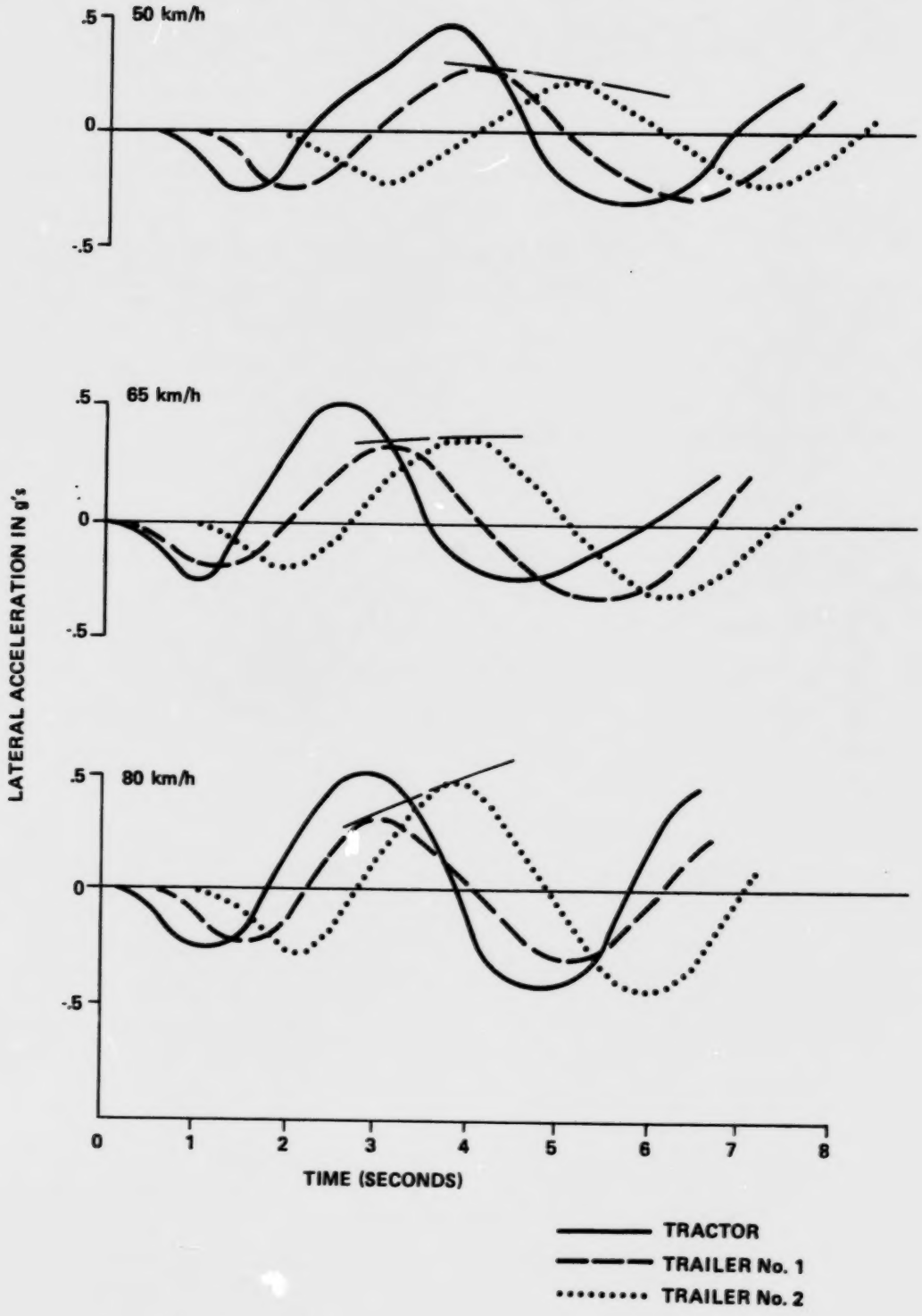


Figure 13/ Typical Plot of Lateral Acceleration vs Time For Twin 45

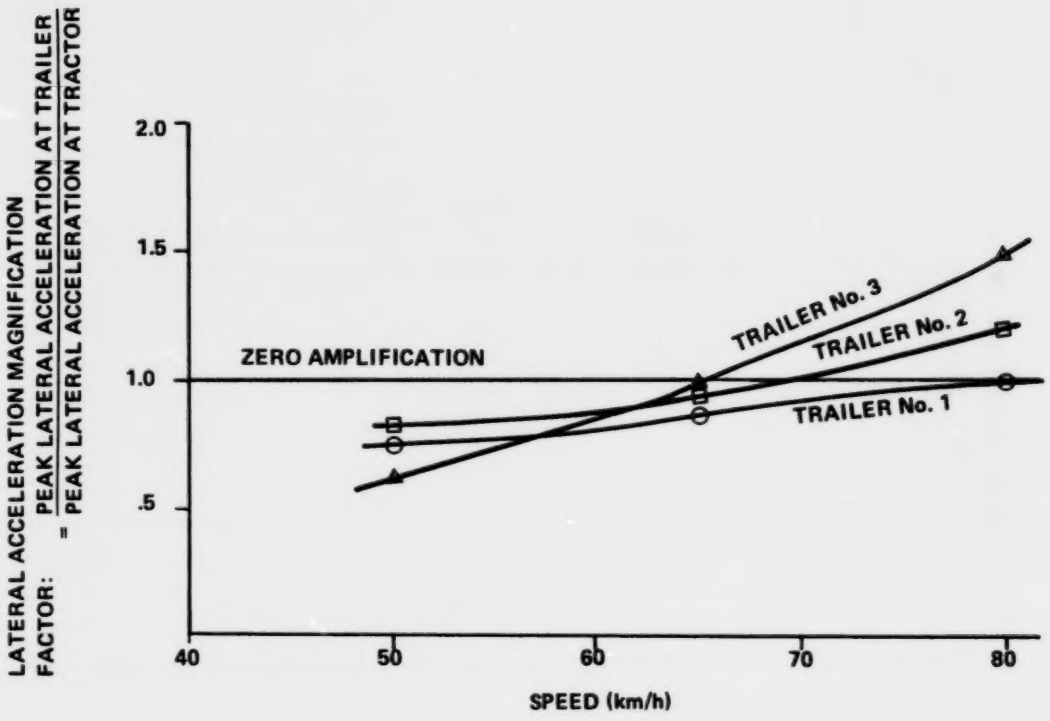


Figure 14a/ Lateral Acceleration Magnification Factor vs Speed for Triple (21 392 kg)

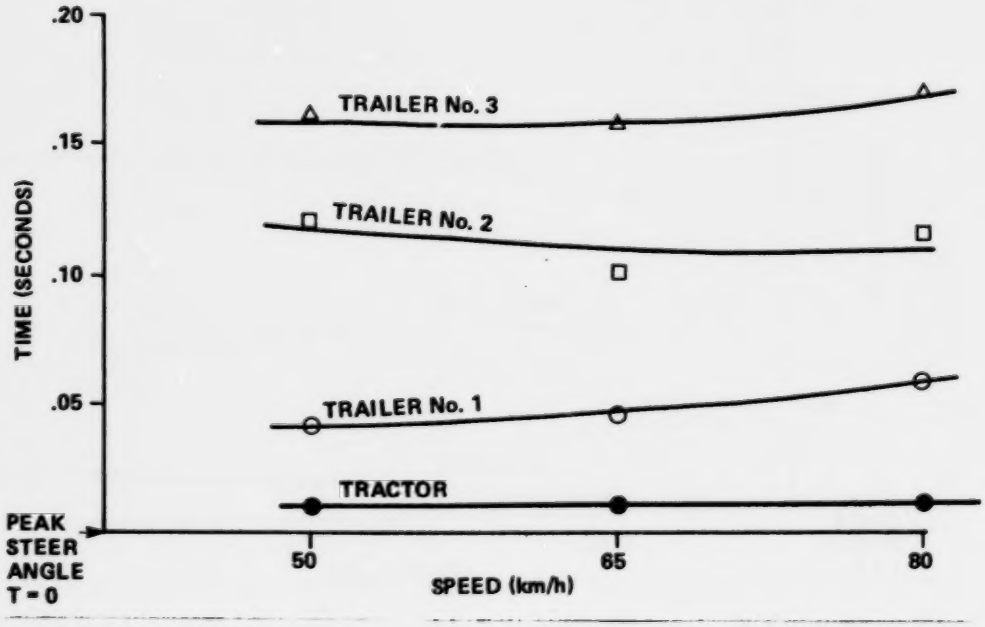


Figure 14b/ Peak Steer Angle to Peak Lateral Acceleration Lag Time at Various Speeds for Triple (21 392 kg)

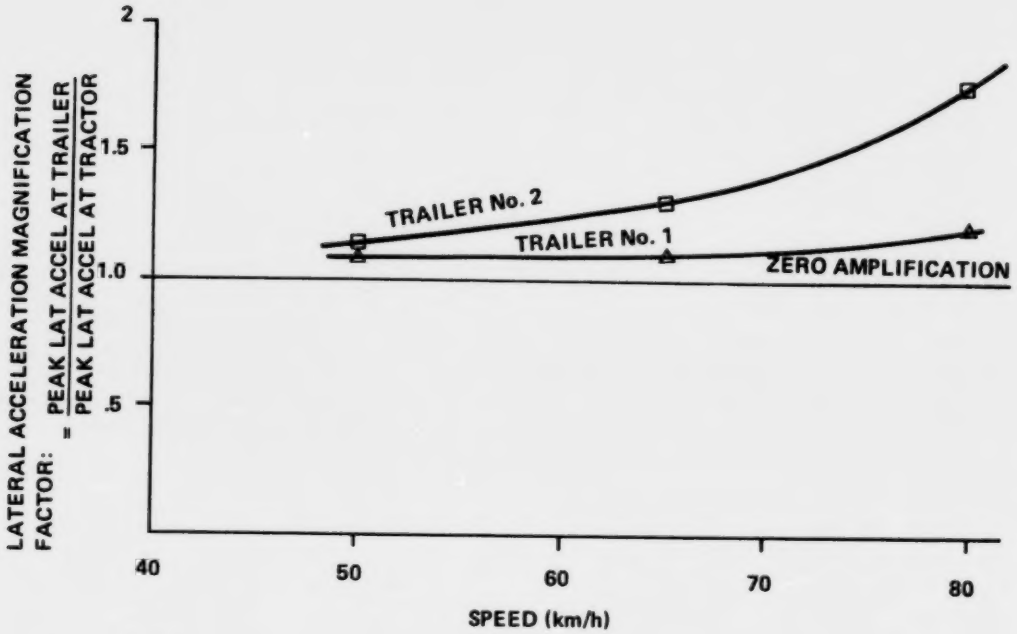


Figure 15a/ Lateral Acceleration Magnification Factor vs Speed for Car Carrier (30 130 kg)

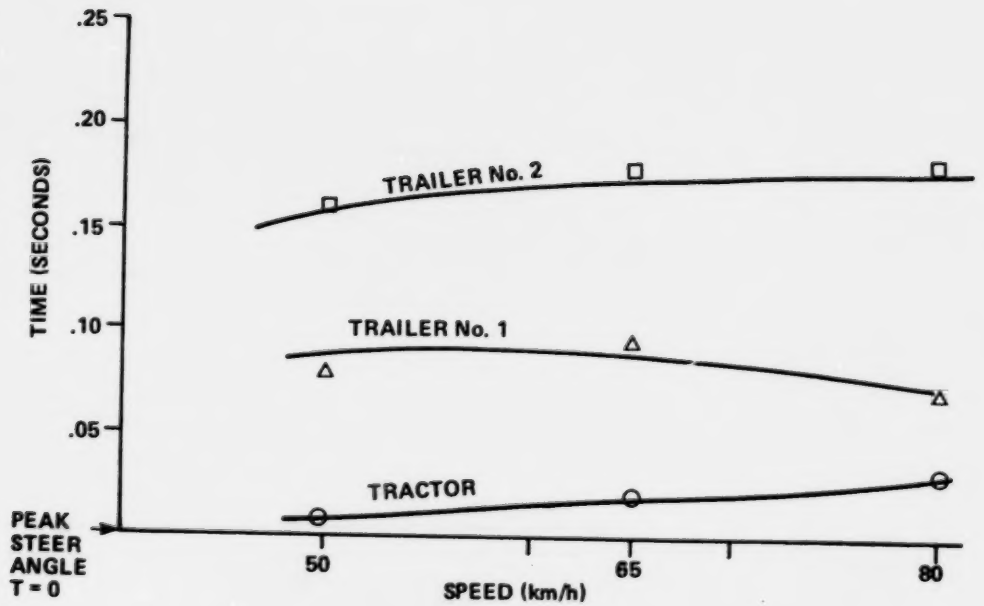


Figure 15b/ Peak Steer Angle to Peak Lateral Acceleration Lag Time at Various Speeds for Car Carrier (30 130 kg)

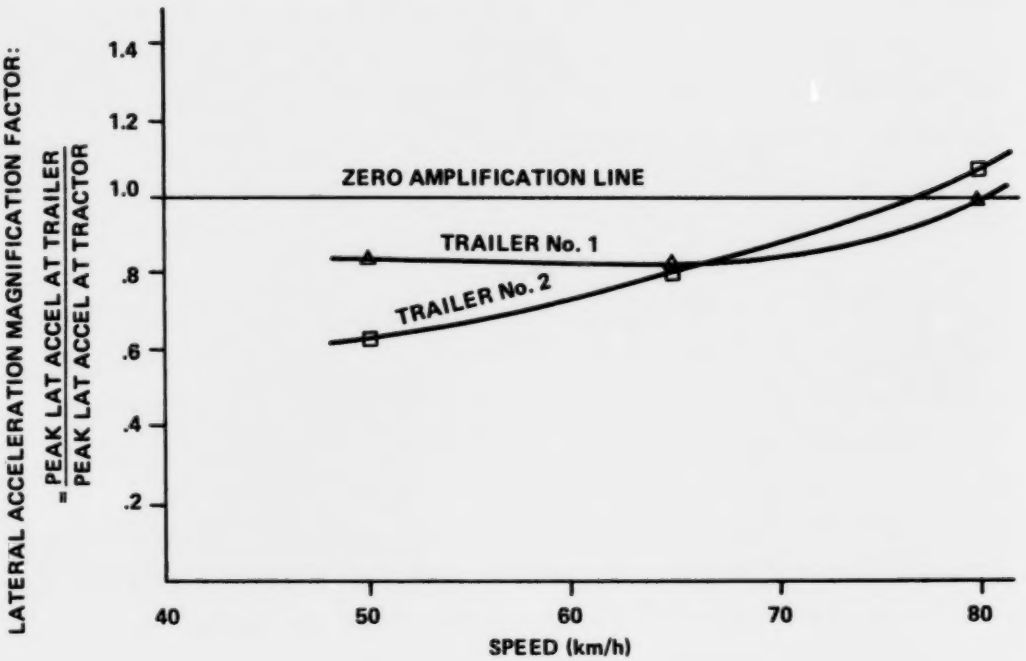


Figure 16a/ Lateral Acceleration Magnification Factor vs Speed for Twin 45 (22 418 kg)

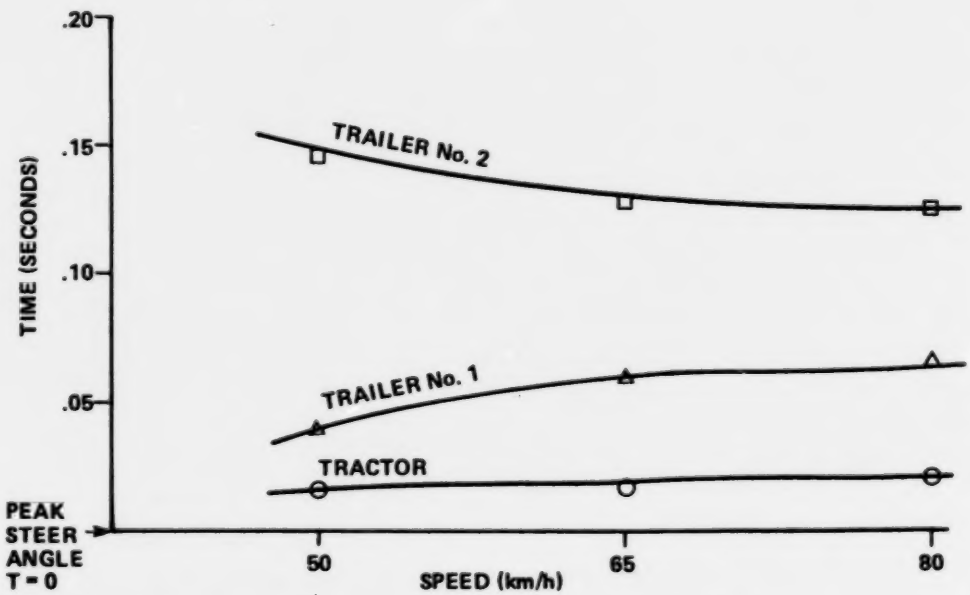


Figure 16b/ Peak Steer Angle to Peak Lateral Acceleration Lag Time at Various Speeds for Twin 45 (22 418 kg)

During the manoeuvres at the highest speed the Car Carrier experienced lifting of the rear trailer wheels and sliding. This vehicle had a very low center of gravity, unladen, and tended to skid laterally before rolling. It provided a very graphic display of trailer swing when pushed to the stability limits. During the manoeuvre, the rear trailer articulation angle became so great that the rear trailer kingpin support assembly struck the rear tail light housing of the lead trailer, with minor damage occurring to each.

Testing of the Twin 45 was conducted more cautiously than for the other two vehicles, with lesser steer inputs producing lower accelerations. Nevertheless, it was evident that the expected mode of instability of this vehicle would be rollover, due to its high center of gravity.

All three vehicles exhibited a tendency to "whiplash" at higher speeds under the severe steer inputs used. Depending on trailer type and suspension characteristics, the response either manifested itself predominantly as trailer roll or trailer swing.

4.2/ Brake Timing

Brake line air pressure time histories were obtained for the following configurations:

1/ MTC tractor and single trailer of the Triple;
2/ MTC tractor and two trailers of the Triple;
3/ MTC tractor and Triple;
4/ MTC tractor and Twin 45; and
5/ MCL tractor and Car Carrier.

The pressures were monitored by transducers mounted in the airline at the rear axle of each unit, and the brake treadle valve. Brake pedal position was also monitored.

Figure 18 and the upper portion of Figures 20 and 21 show the application pressure time histories, while Figure 19 and the lower portion of Figures 20 and 21 are the release pressure time histories.

Figure 17/ Car Carrier and Triple Shown Executing Double Lane Change

Current industry practice measures brake application time from motion of the treadle until 414 kPa (60 psi) is reached, and brake release time as the time to release pressure from 655 to 35 kPa (95-5 psi), with a 690 kPa (100 psi) system pressure [4].

From Figures 18 and 19 it was noted that as trailers are added to the Triple, brake application and release times both increased.

The application times and their relative sequence is shown in Figure 22. For the Triple and Car carrier, gaps are seen in brake sequencing, where the tractor has full braking but the trailers have none.

Figure 23 shows release sequencing and durations. All vehicles tested, with the exception of the single trailer of the Triple braked the tractor prior to braking the train. All vehicles tested released the tractor brakes first, with all trailer brakes releasing essentially together.

Brake application testing was done with three brake applications of the tractor air system. After each application pressure was lost. It was noted that this variable pressure at the tractor affects brake application time. All brake lines for single, double and triple 8.23 m trailer combinations were averaged at each supply pressure tested, and the net effect is shown in Figure 24. This shows that as supply line pressure decreases, brake application time increases.

Brake timing on the Car Carrier was obtained by the owner prior to the MTC test. This data is included as the dotted line on Figure 20.

4.3/ Stopping Distance

The three vehicles were each driven at a speed of 32 km/h on dry pavement, and subjected to maximum braking. To indicate when the brake was applied, a marker gun loaded with a paint charge, attached to the vehicle and directed at the ground, was fired from the brakelight signal. This marked the pavement at the point of brake application, and when the vehicle had come to a stop a second shot was fired manually. The distance between paint marks was recorded as the stopping distance. The gun is shown in Figure 26. About six runs were made for each vehicle and the results are recorded in Table 4 and Figure 25.

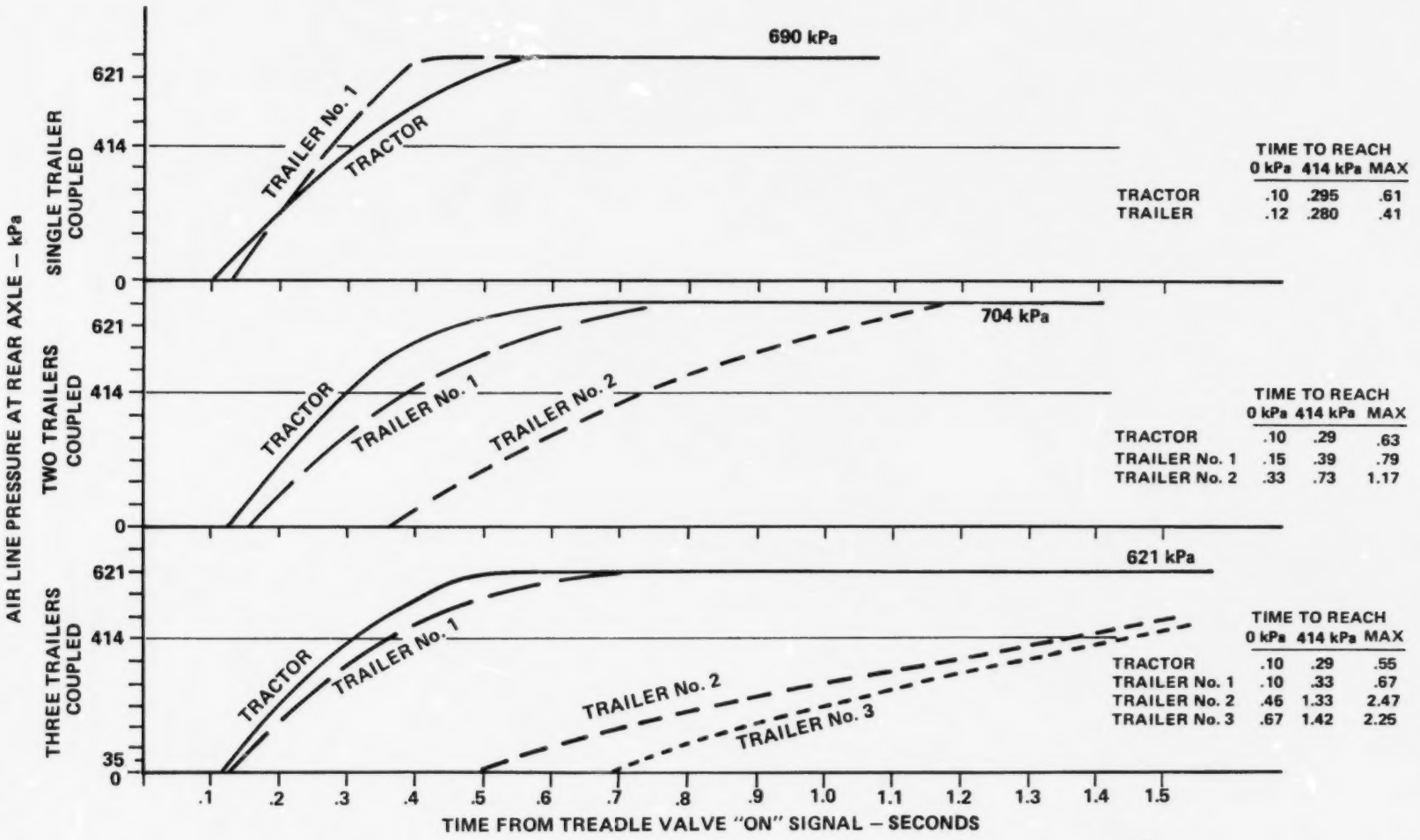

AIR LINE PRESSURE AT REAR AXLE – kPa
SINGLE TRAILER COUPLED
TWO TRAILERS COUPLED
THREE TRAILERS COUPLED
621
414
35
0
690 kPa
704 kPa
621 kPa
TRACTOR
TRAILER No. 1
TRAILER No. 2
TRAILER No. 3
TIME TO REACH
0 kPa 414 kPa MAX
TRACTOR .10 .295 .61
TRAILER .12 .280 .41
TRACTOR .10 .29 .63
TRAILER No. 1 .15 .39 .79
TRAILER No. 2 .33 .73 1.17
TRACTOR .10 .29 .55
TRAILER No. 1 .10 .33 .67
TRAILER No. 2 .45 1.33 2.47
TRAILER No. 3 .67 1.42 2.25
.1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1 1.2 1.3 1.4 1.5
TIME FROM TREADLE VALVE "ON" SIGNAL – SECONDS

Figure 18/ Air Brake Pressure Application Times for One, Two, and Three Interconnected 8.23 m (27 ft) Trailers

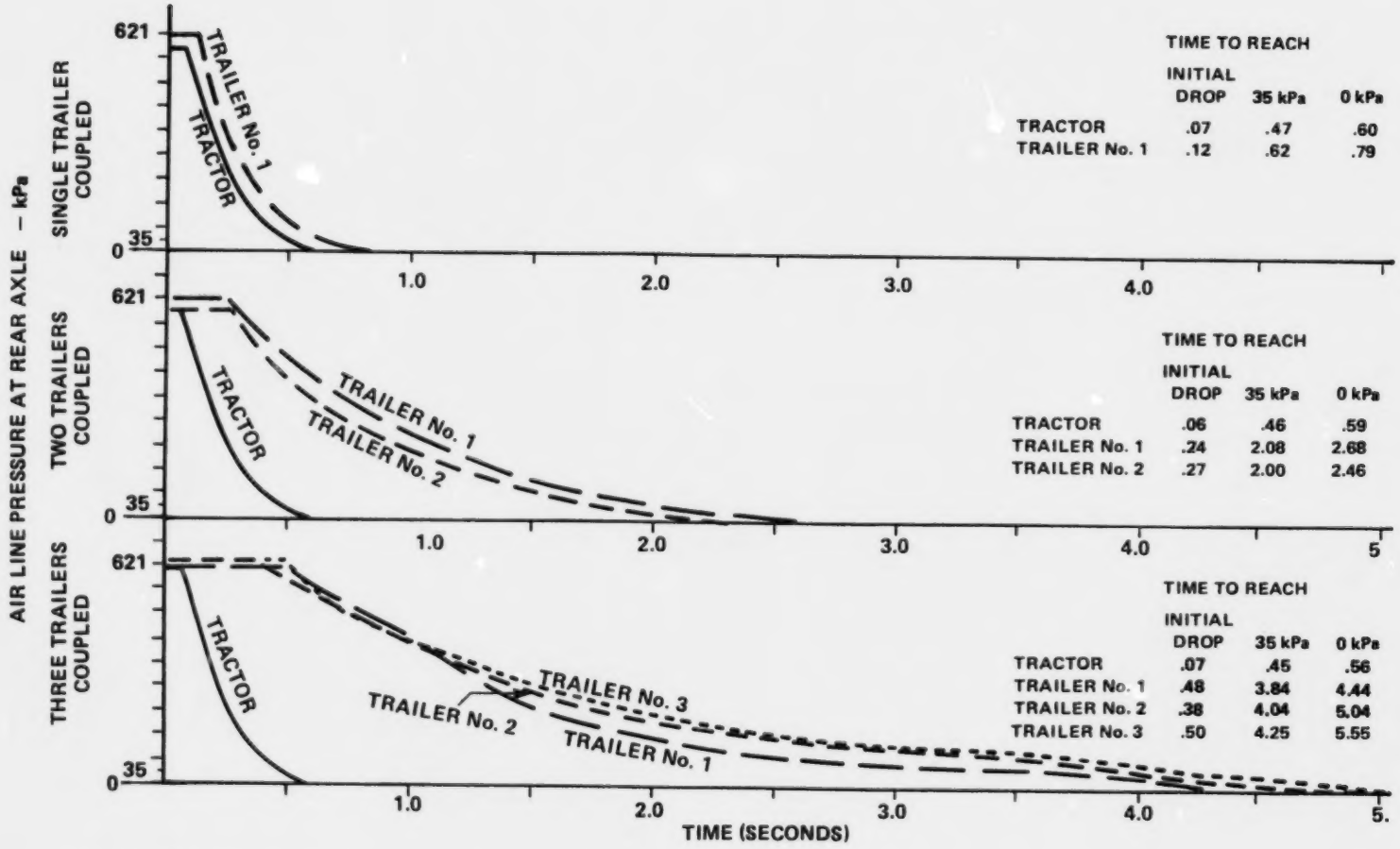


Figure 19/ Air Brake Pressure Release Times for One, Two, and Three Interconnected 8.23 (27 ft) Trailers

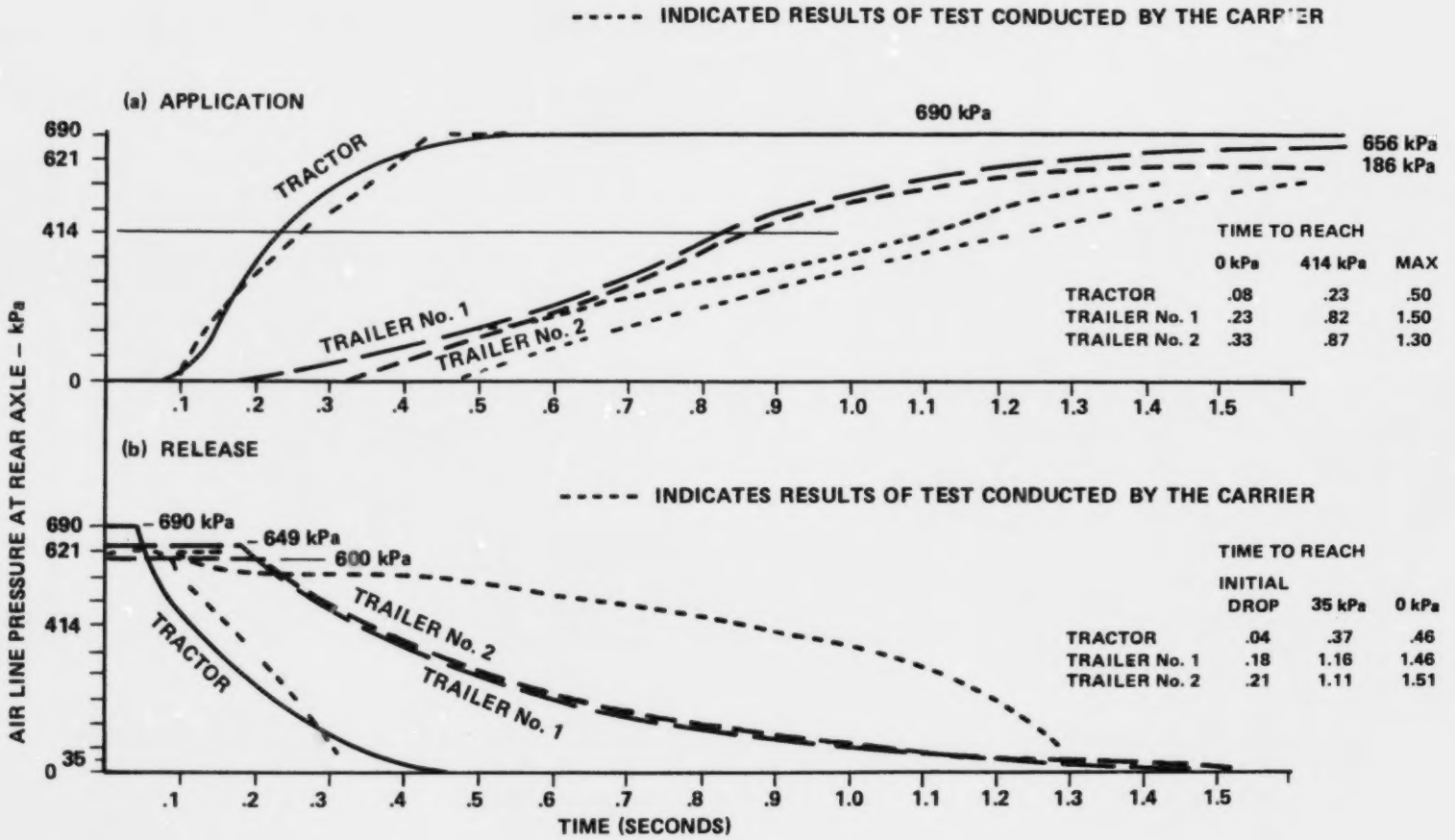


Figure 20/ Air Brake Pressure Application and Release Times for Car Carrier

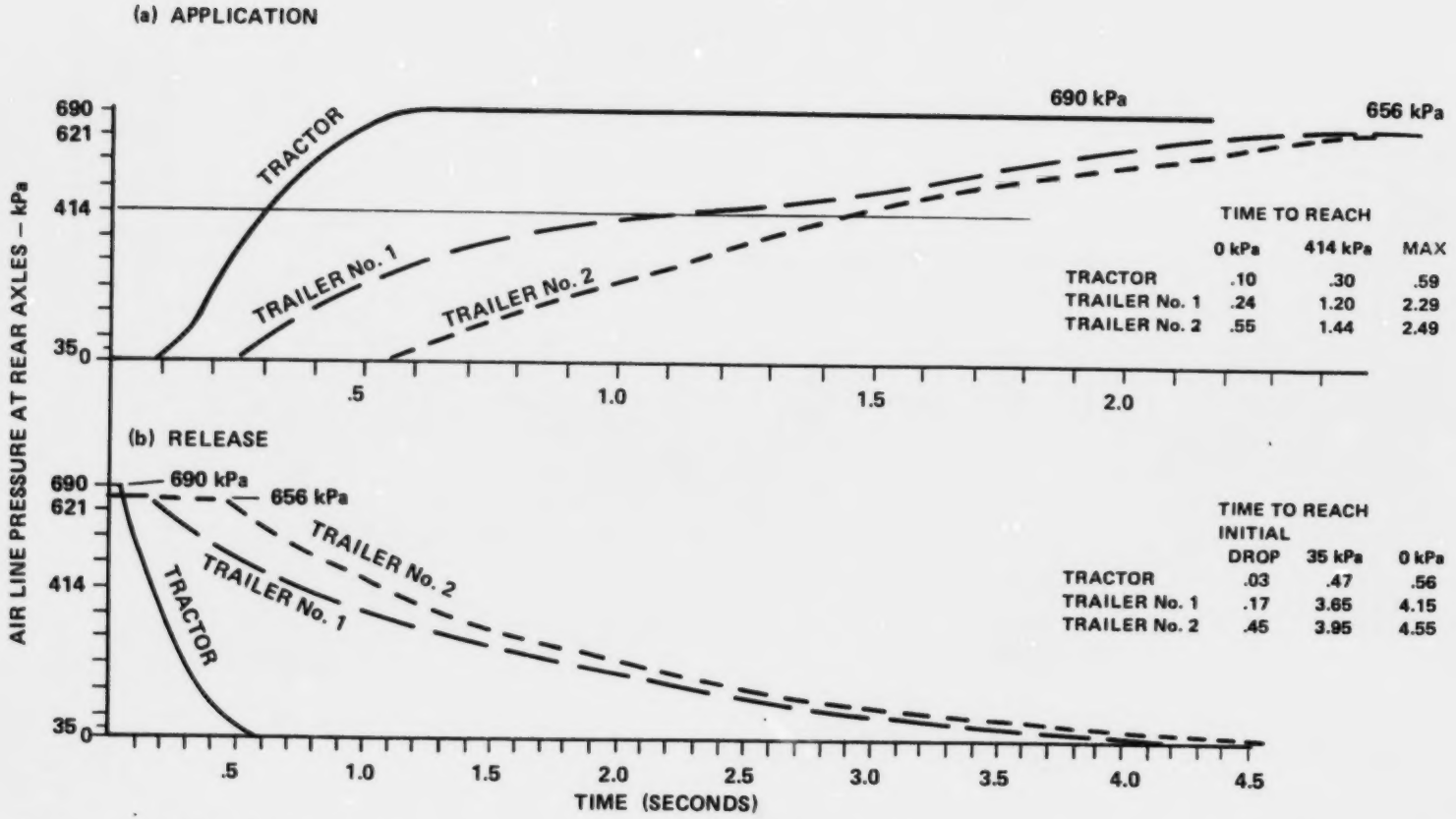


Figure 21/ Air Brake Pressure Application and Release Times for Twin 45

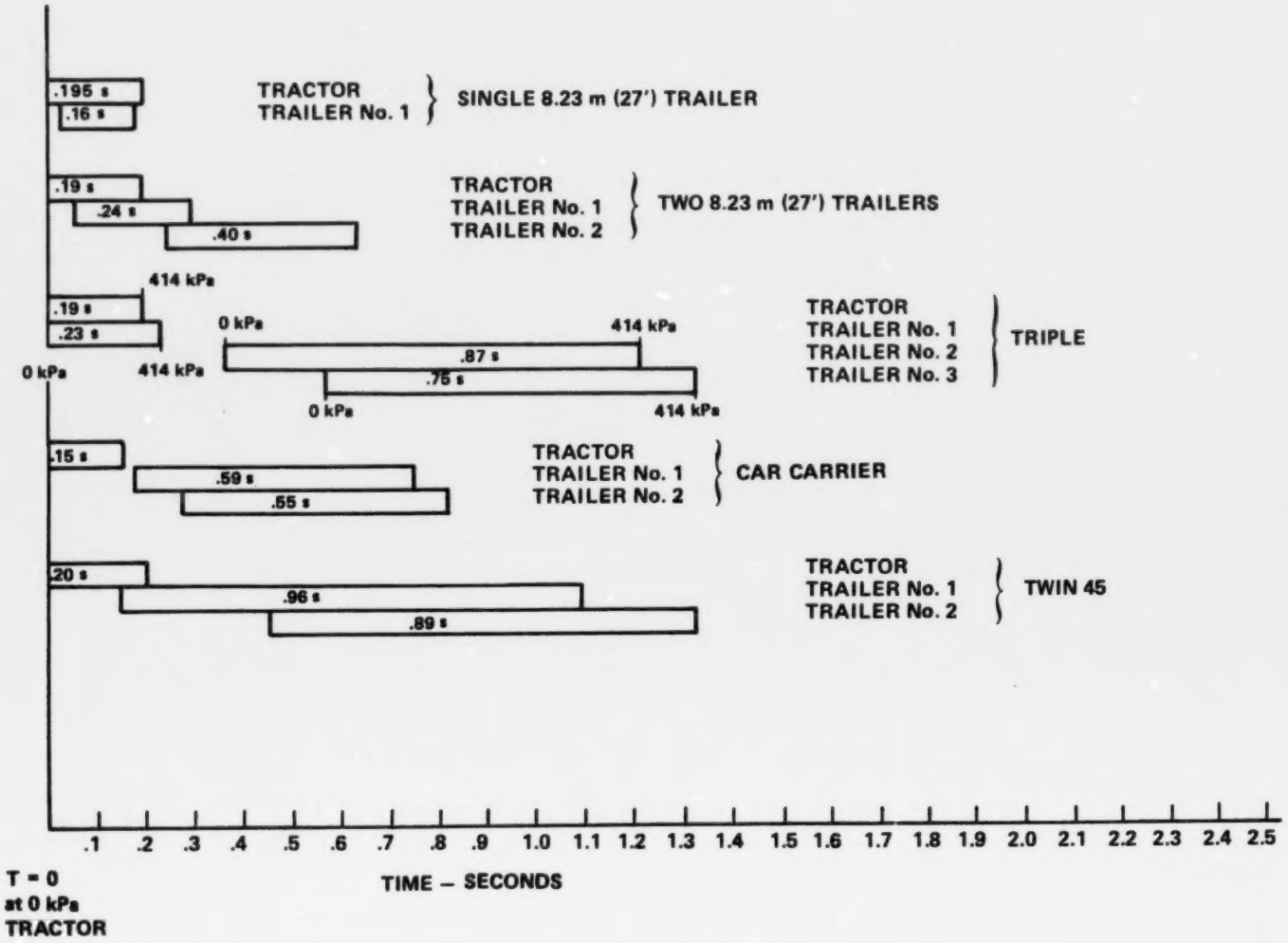


Figure 22/ Brake Application Sequence and Duration at Rear Axle for Five Combinations

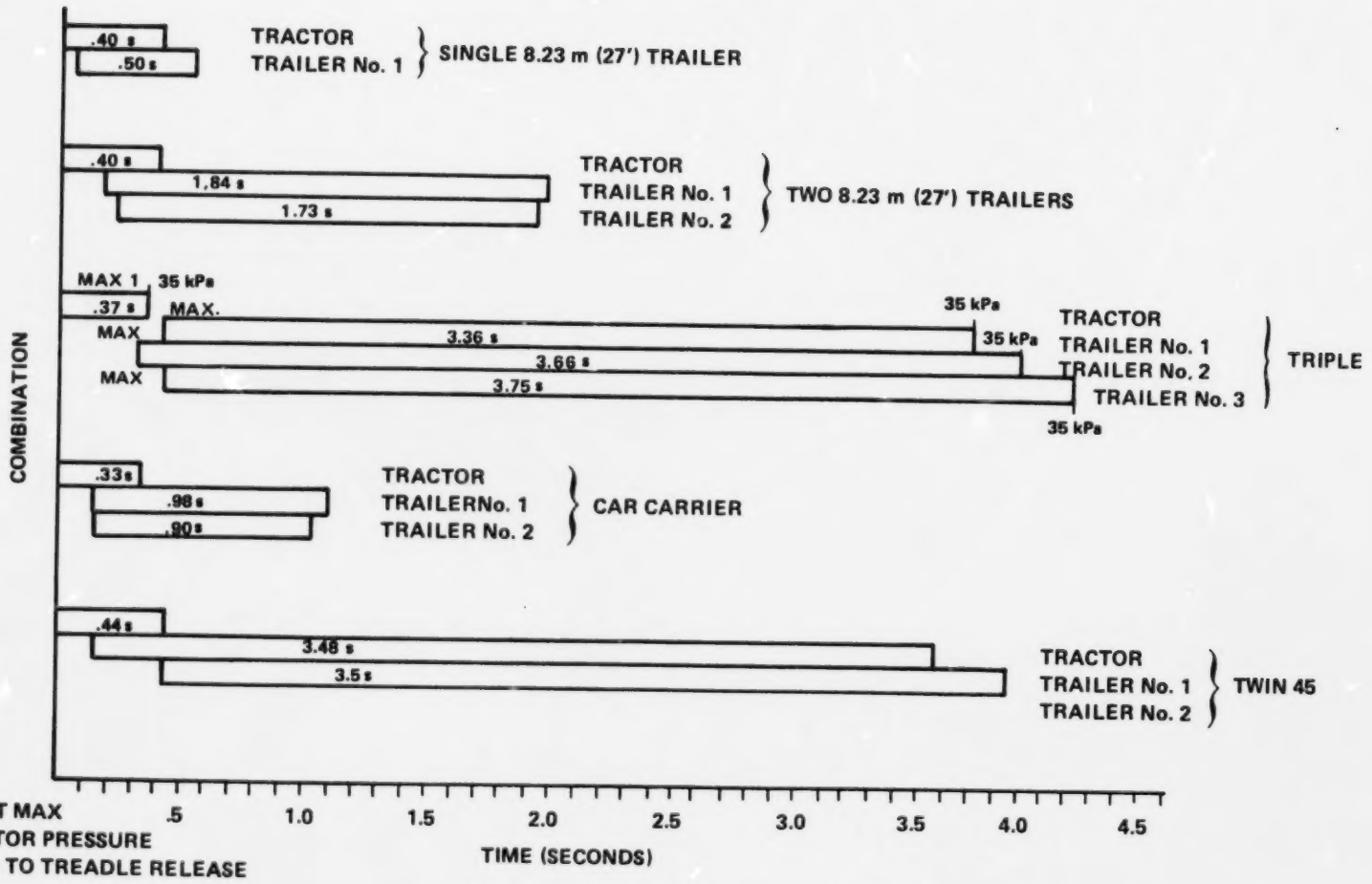


Figure 23/ Release Sequence and Duration Axles for Five Combinations

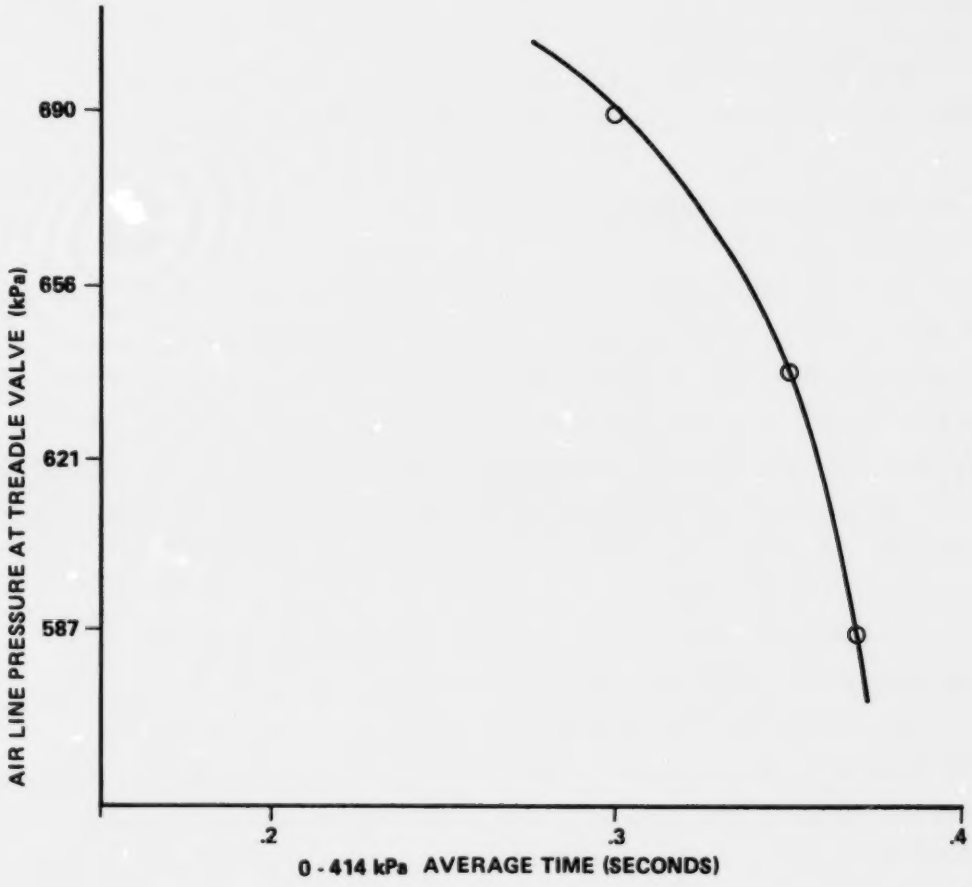


Figure 24/ Effect of Supply Line Air Pressure on Average Brake Application Times (0-60 psi)

The Triple showed the shortest stopping distance in all runs. In most cases the wheels locked, which was expected with an empty vehicle. The Twin 45 showed a fairly constant stopping distance with higher distances recorded when the tractor experienced "wheel hop", a phenomenon caused partially by suspension design and low trailer loads. The Car Carrier yielded the longest stopping distances. Tractor and rear trailer axle lock-up was evident in almost all cases, due to the unloaded state of the vehicle. The stopping distances were relatively uniform throughout all runs.

The results are consistent with the conditions of empty vehicle, a surface skid number of about 60, and relative vehicle mass.

4.4/ Response to Lane Change

During the road demonstration on Highway 401 the overlength vehicles were directed to change lanes at speed. Factors such as crosswinds, grades and curves in the roadway therefore had an effect on the overall vehicle response, as did the minor irregularities in the road surface. It must be assumed that the drivers introduced similar steering inputs during the vehicle manoeuvres, and the vehicles were all subject to the same influencing factors.

The Triple exhibited rear trailer sway during both passing and lane change maneouvres. The sway amplitude appeared small but perceptible, and lasted several oscillations before inherent damping prevailed. It was further observed that the rearmost trailer of the train would sway momentarily after cresting a hill and beginning the downhill run. This may have been due to relaxation of the longitudinal load allowing some slack action at the kingpin or dolly hitch.

The Twin 45 experienced trailer sway to a lesser degree than the Triple. The bogies of this vehicle's trailers were moved to its foremost position. The shortened wheelbase of this vehicle contributed to its manoeuvrability during slow speed operation.

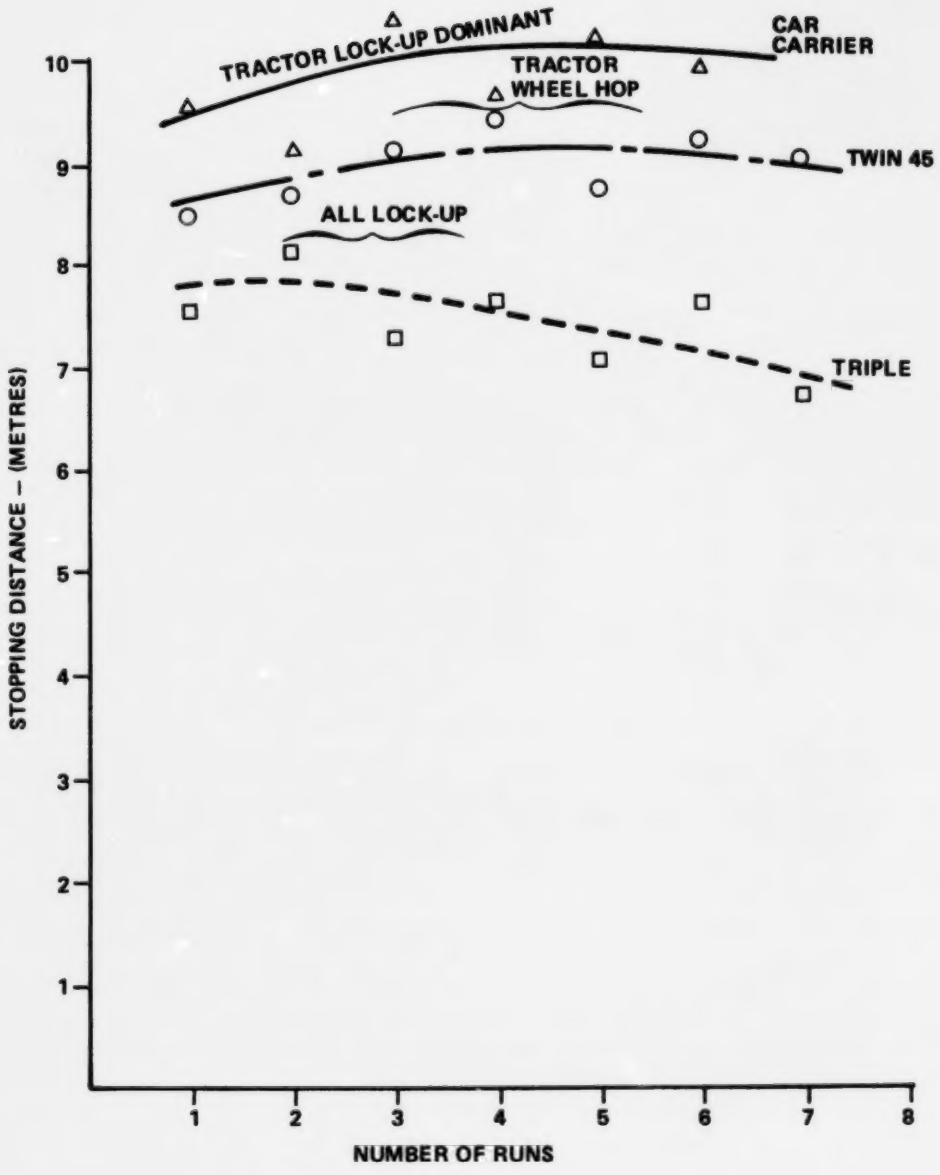
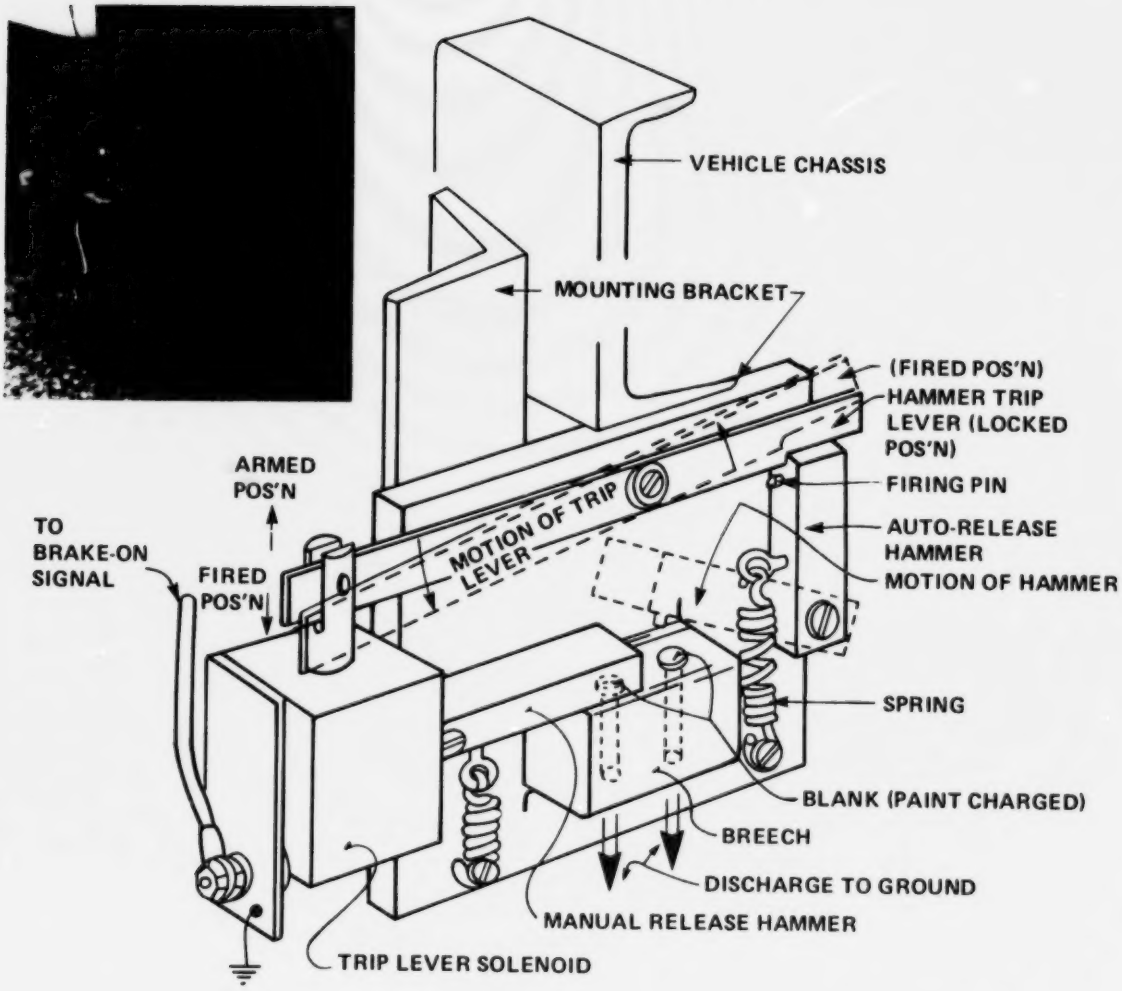


Figure 25/ Stopping Distance (Metres)



METHOD OF OPERATION

To arm, charges are loaded in the breech and auto hammer is preset in cocked position. A signal from the vehicle brake system causes the solenoid to activate thereby releasing auto-release hammer (through trip lever) to strike paint charge. Blank discharges to surface and leaves a residue mark suitable for identification purposes. When the vehicle is stopped, the manual release hammer is deployed to discharge second blank. Stopping distance is then measured as the distance between paint residue marks.

Figure 26/ Stopping Distance Marking Gun

Table 4/ Stopping Distance Recordings

RUN NUMBER	STOPPING DISTANCE (METRES)		
	CAR CARRIER	TWIN 45	TRIPLE
1	9.57	8.53	7.58
2	9.12	8.72	8.16
3	10.38	9.18	7.30
4	9.65	9.45	7.70
5	10.23	9.18	7.11
6	9.98	8.75	7.60
7		9.45	6.74
8		9.08	

Figure 27/ Overlength Trucks on Highway 401

The Car Carrier demonstrated the least sway of all three test vehicles during "on-road" operation. The stability of this particular combination is due largely to the fact that it has only two articulation points, compared to five on the Triple and three on the Twin 45. The combination exhibited a small amount of "dog tracking", the rear trailers operating at a crab angle, which was not evident for the other trucks. The effect is possibly due to a roll steer phenomenon due to interaction of its air suspension with roadway crossfall, and/or high overhung loads resulting in an increased axle load generating misalignment between axles. The "dog tracking" was less pronounced on recently paved sections of the highway.

The lane changing characteristics of the trains appeared comparable to that of other trucks on the highway at the same time. Slight swaying effects are not necessarily an indication of a low stability threshold. All trains moved into and out of lane effectively and smoothly during the demonstration.

4.5/ Interaction With Other Traffic

During the demonstration on Highway 401 the reactions and interactions between the overlength vehicles and other highway traffic was observed and recorded. The demonstration was conducted without advance warning, so traffic on the highway was not expecting atypical trucks.

All trucks passed and were passed by various sized automobiles. During the overtaking exercise there were no noticeable indications of aerodynamic buffetting over that normally sustained from tractor trailers. The effects of air displaced by the overlength trucks on MTC's full size station wagon was negligible. There was no indication that trailing wakes and vortices generated by the overlength vehicles were greater than those produced by normal semi-trailer combinations. Particulate generation due to the aerodynamic wake was therefore judged not different from that created by normal highway traffic.

Different drivers in the overlength trucks exercised different strategies in negotiating the ramps off and on Highway 401. Each truck, according to its offtracking characteristics occupied different portions of a ramp while manoeuvering, and minor deviations toward the shoulders were noted.

A rain shower toward the end of the demonstration allowed a visual evaluation of the splash and spray generated by the overlength trucks. Traffic response to the overlength vehicles in these conditions was such that it was impossible to discern any difference in the technique exercised by automobile drivers between passing a single or overlength truck.

The manoeuvring ability of the trucks were such that they tended to interface very effectively with the traffic on the 401 that day. Passing automobile drivers appeared not to notice the fact that the vehicles overtaking them were of abnormal size. Movements in and out of heavy traffic situations were executed efficiently and with no evident hazard.

The effect of the overlength vehicles on the normal traffic flow was minimal. The vehicles appeared to be accepted, and their performance was such that their presence for the most part went unnoticed.

4.6/ Splash and Spray

The Car Carrier was fully equipped with National Rubber "Rain Trapper" anti-spray mudflaps and the wheels were enclosed by metal fenders, shown in Figure 28.

The Twin 45 had "Rain Trapper" anti-spray mudflaps on the tractor and standard mudflaps on the trailers.

The Triple had standard mudflaps on both tractor and trailer.

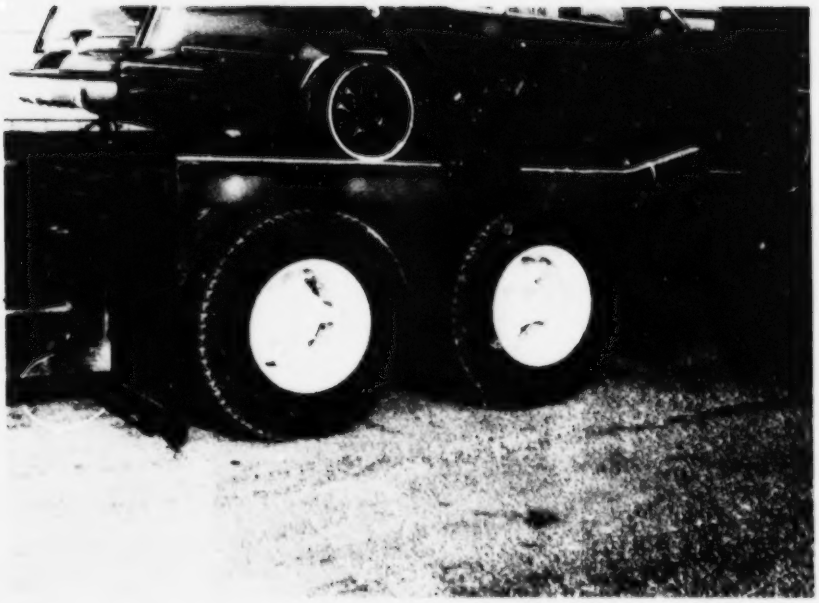
A test was conducted at Centralia in a dry atmosphere on a wetted asphalt test strip. Each vehicle made two passes at 72 km/h and was observed from in front and from above. The Car Carrier appeared to generate the

smallest spray plume. Spray was generated at relatively low levels, below 0.75 m, and extended out approximately 2 m. It was felt that the "side wave" effect of the front tractor wheel contributed greatly to the spread of the plume. The spray suppression devices tended to reduce the overall magnitude of the spray envelope. Aerodynamic flow around and under the vehicle did not lift the spray vortex appreciably as the plume progressed down the vehicle length. Wake effects were minimal in the unloaded configuration due to its space frame design.

The Twin 45 tended to generate a spray plume slightly higher than 1 m which projected out approximately 3 m from the wheels. The spray was more substantial than that generated by the car carrier in wake size, spread, density and overall effect. Aerodynamic flow tended to lift the plume as it progressed the length of the truck hence generating a sizeable airborne wake. What was apparently gained by using a tractor installed with anti-spray was soon lost to trailers not so equipped.

The Triple appeared to create the greatest spray. The spray generated appeared to be of the same frontal dimensions as that of the Twin 45, but was initiated rather close to the front of the vehicle and showed less tendency to settle. It appeared rather consistent along the length in terms of density and spread, and the trailing wake was similar to that of the Twin 45. Figure 29 shows the comparative effects of the spray generated by the test vehicles at Centralia.

The demonstration on Highway 401 was conducted partially in rain showers. The Car Carrier at this time was laden with automobiles, as opposed to the empty vehicle tested at Centralia, and it was noted that during rain the wake effect was similar to that of the other two overlength vehicles. The moisture present on the 401 was as a result of falling rain entrapped in the slipstream, water flowing from the surfaces of the truck, and ground spray generated by tire ground interaction, and not just the latter as demonstrated at Centralia. During the rainy portion of the 401 demonstration it was observed that the spray generated by the test vehicles was not worse than that generated by standard tractor/trailer configurations operating that day at similar speeds. The driver of an automobile passing or being passed by an overlength vehicle



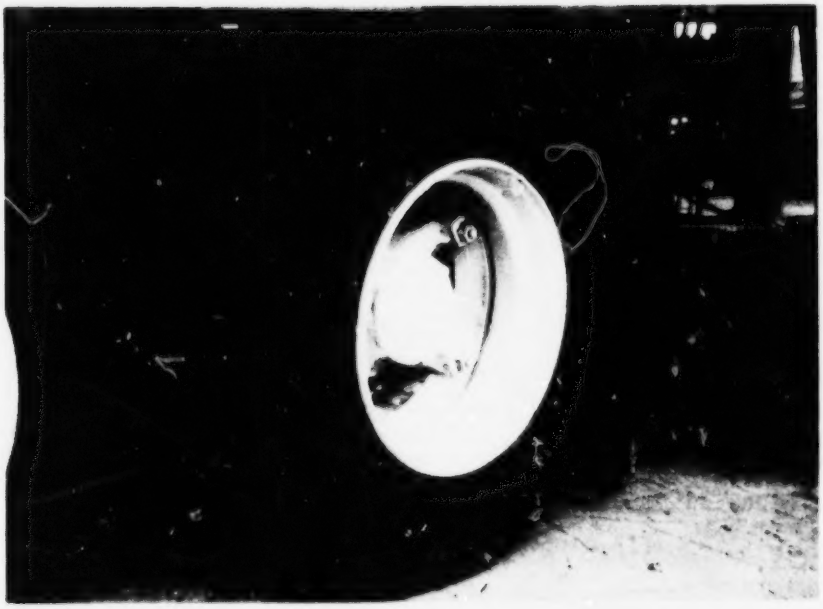


Figure 28/ Anti-Spray Guards on Car Carrier

Figure 29/ Comparative Spray of Test Vehicles

would be subject to poor visibility and increased noises, due to spray, for a slightly longer duration because of the increase of overtaking distance and time.

4.7/ Offtracking

4.7.1/ Constant Radius Test

The test vehicles approached a 29.87 m radius circle tangentially and commenced a clockwise turn about its centre. When the vehicle had proceeded 60 degrees into the turn an initial measurement from the circle centre to the right rearmost wheel set of the train was made. The vehicle then continued and stopped at increments of 30 degrees for like measurements. When the train had apparently reached steady state conditions, by stabilization of measurement, distances from the turn centre to all right wheel sets of each axle was measured. This data is recorded in Table 5 and shown in Figure 30.

The Twin 45 with long wheel base offtracked the greatest, and the single 45 offtracked the least. By shortening the wheelbase of the Twin 45 the maximum offtracking was reduced by 24 1/2% and stabilized earlier. The Triple offtracked least, 2.905 m, but took longest to stabilize. The Car Carrier offtracked 3.09 m.

All trains stabilized between 210 and 270 degrees. Figures 31 to 34 show the stabilized position of all configurations tested.

4.7.2/ Swept Path Test

The test vehicles negotiated a 90° right turn with 9.14 m curb radius. Markers were placed adjacent to the track followed by the front bumper (left edge) and the rearmost right tire of the train. Marker locations were measured to generate the swept paths shown in Figures 36 to 40. Swept width measurements were taken normal to the curb at 17 equidistant points along the curb, and are illustrated on Figure 41.

The Car Carrier and the Twin 45 indicated a maximum tracking line at approximately station 13 due to a left turn of the tractor for alignment into the outbound lane. When this occurred, the maximum tracking line ceased to be the tractor front bumper and became the rear of the first

trailer. This tracking line is shown on Figures 36, 38 and 39. The car carrier reached limiting articulation, due to structural contact, between the two trailers during this test.

The dotted lines on Figures 36 to 40 indicate typical 3.66 m (12 ft) lane marker lines. At such an intersection the train would sweep into the adjacent lanes in order to negotiate the turn. The intrusions, measured by lane length, track length, swept area and maximum width while in the adjacent lane are shown in Figure 42.

The nature of the turns made with the Car Carrier and short wheelbase Twin 45 was such that the rear wheel tracked approximately 1 m from the curb. The data for these runs was corrected to a track distance of 0.25 m from the curb for comparison purposes.

Of the vehicles tested the Twin 45, with long wheelbase, showed the greatest tendency to occupy the adjacent lane while turning. Reducing the wheelbase reduced the swept area of the adjacent lane by 34%. The Triple showed the least tendency to occupy the adjacent lane. The single semi showed the least lane occupation of the trucks tested by indicating a decrease in swept area over the Triple by 43%.

The maximum occupied width of the adjacent lane varies from 4 m with the single 45 to 8.5 m with the long wheelbase Twin 45. It is interesting to note that the maximum occupied width of the adjacent lane for the Triple and Car Carrier is identical.

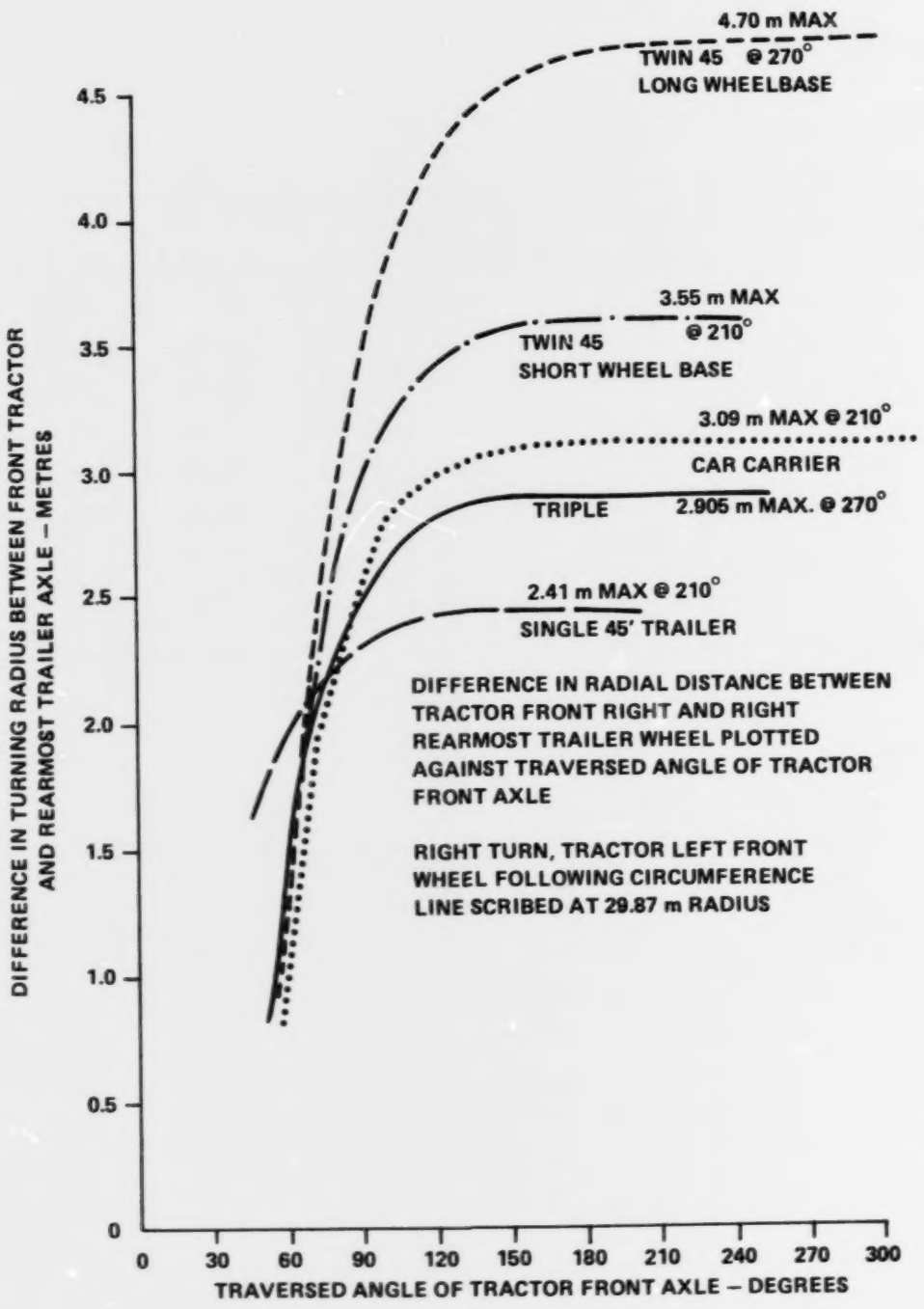


Figure 30/ Transient Offtracking Characteristics

Table 5/ Constant Radius Offtracking

RECORDINGS

TRANSIENT

ANGULAR DISTANCE THROUGH TURN DEGREES	RADIUS AT REAR WHEELS (m)				
		TWIN 45			
	CAR CARRIER	LONG	SHORT	TRIPLE	MTC & 45
60°	26.55	26.37	26.2	26.48	25.57
90°	25.04	24.18	24.67	25.09	25.24
120°	24.59	23.34	24.18	24.75	25.13
150°	24.47	23.02	24.02	24.69	25.13
180°	24.43	22.94	24.02	24.68	25.25
210°	24.46	22.94	24.02	24.69	25.16
240°	24.49	22.92		24.68	
270°		22.88		24.68	
300°		22.88			

STEADY STATE

AXLE NUMBER	RADIUS TO INNER WHEEL (m)				
		TWIN 45			
	CAR CARRIER	LONG	SHORT	TRIPLE	MTC & 45
1	27.60	27.60	27.60	27.58	27.57
2	26.94	27.26	27.27	27.21	27.19
3	26.94	27.25	27.25	26.38	27.18
4	25.71	25.21	25.67	26.34	25.18
5	25.69	25.18	25.65	25.49	25.16
6	24.53	25.16	25.75	25.48	
7	24.49	22.92	24.06	24.68	
8		22.88	24.02		

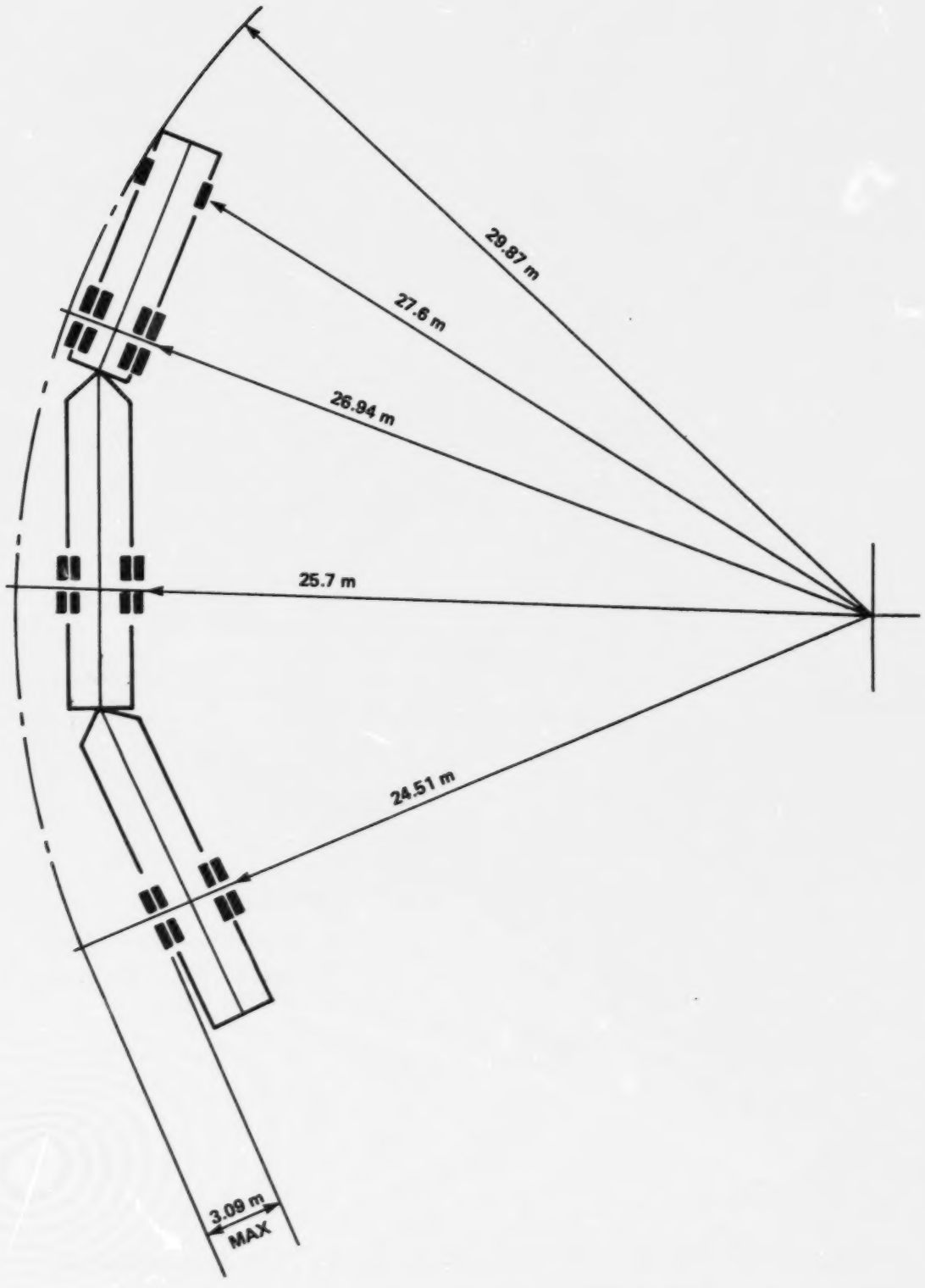


Figure 31/ Car Carrier Steady State Offtracking Regime on 29.87 m Radius Pad

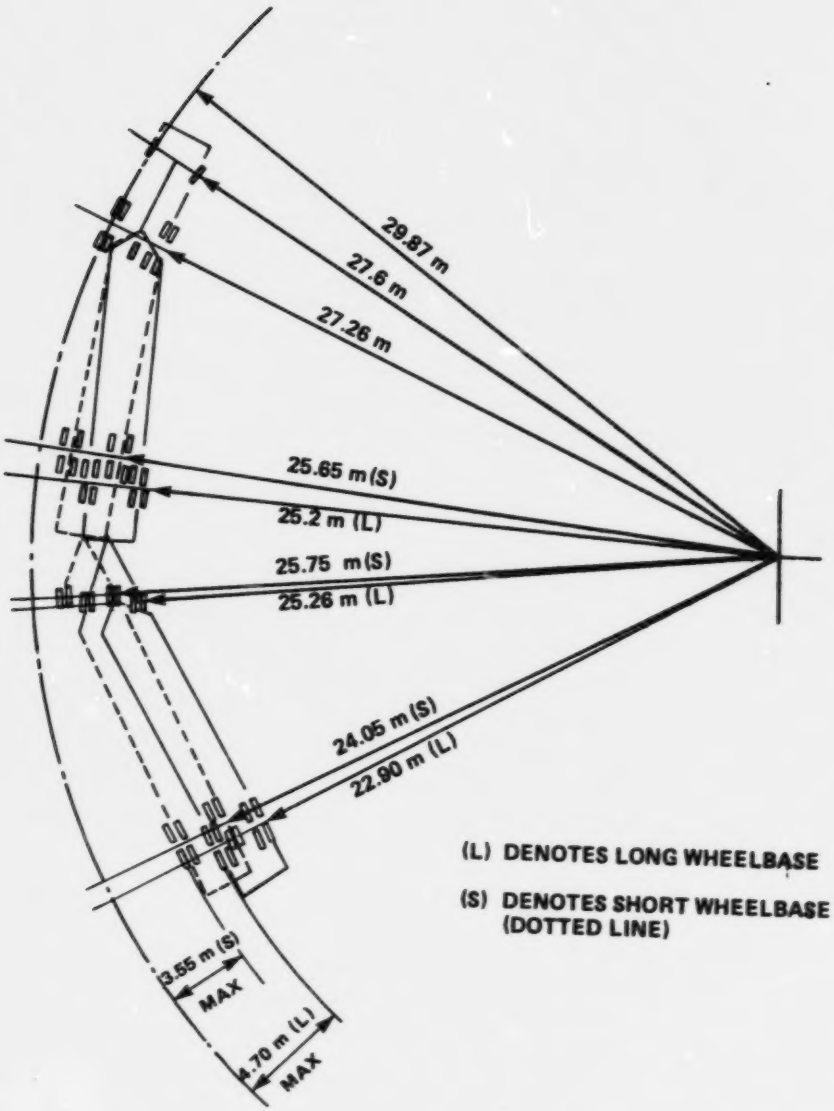


Figure 32/ Twin 45 Combination Steady State Offtracking Regime on 29.87 m Radius Pad

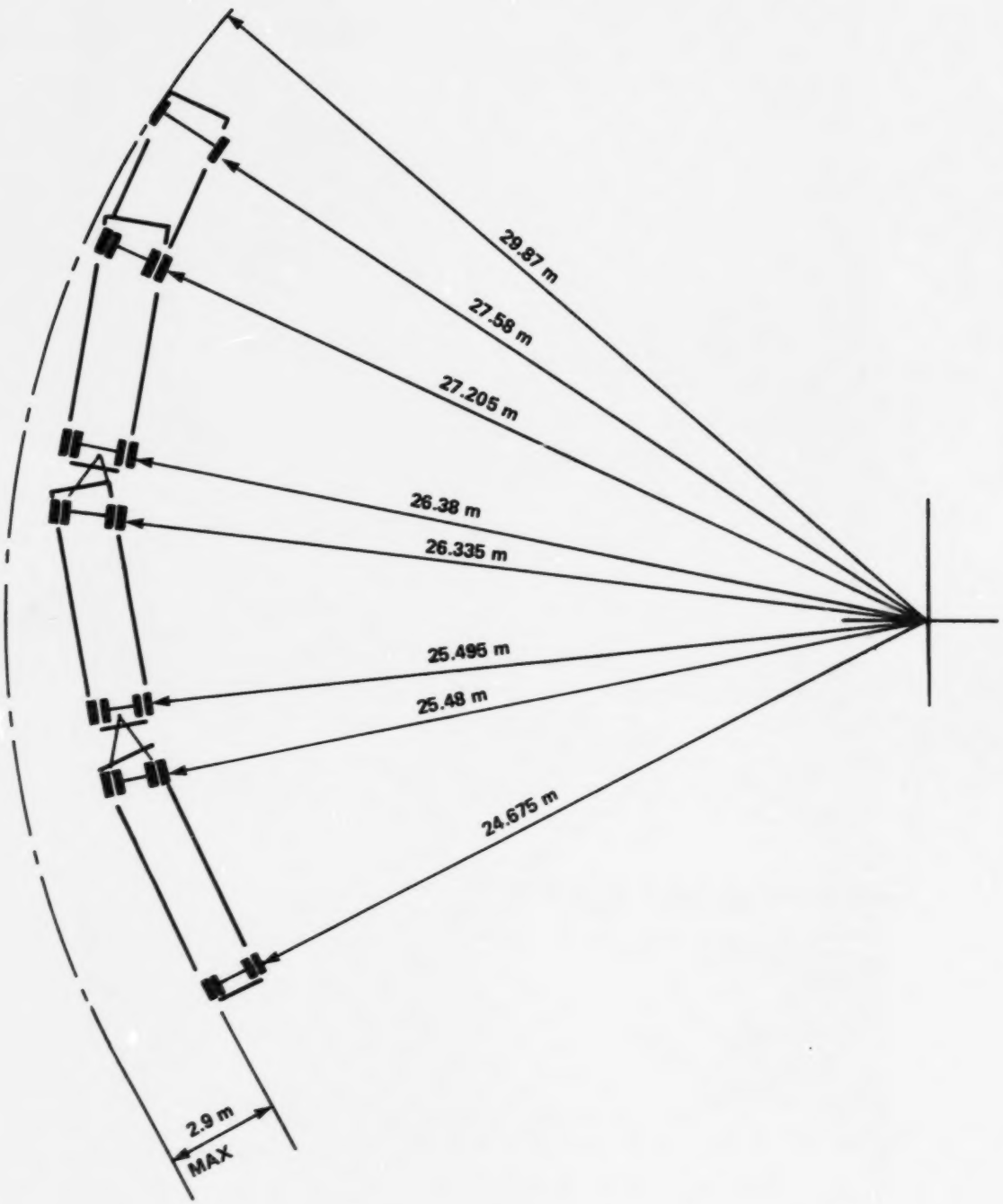


Figure 33/ Triple Steady State Offtracking Regime on 29.87 m Radius Pad

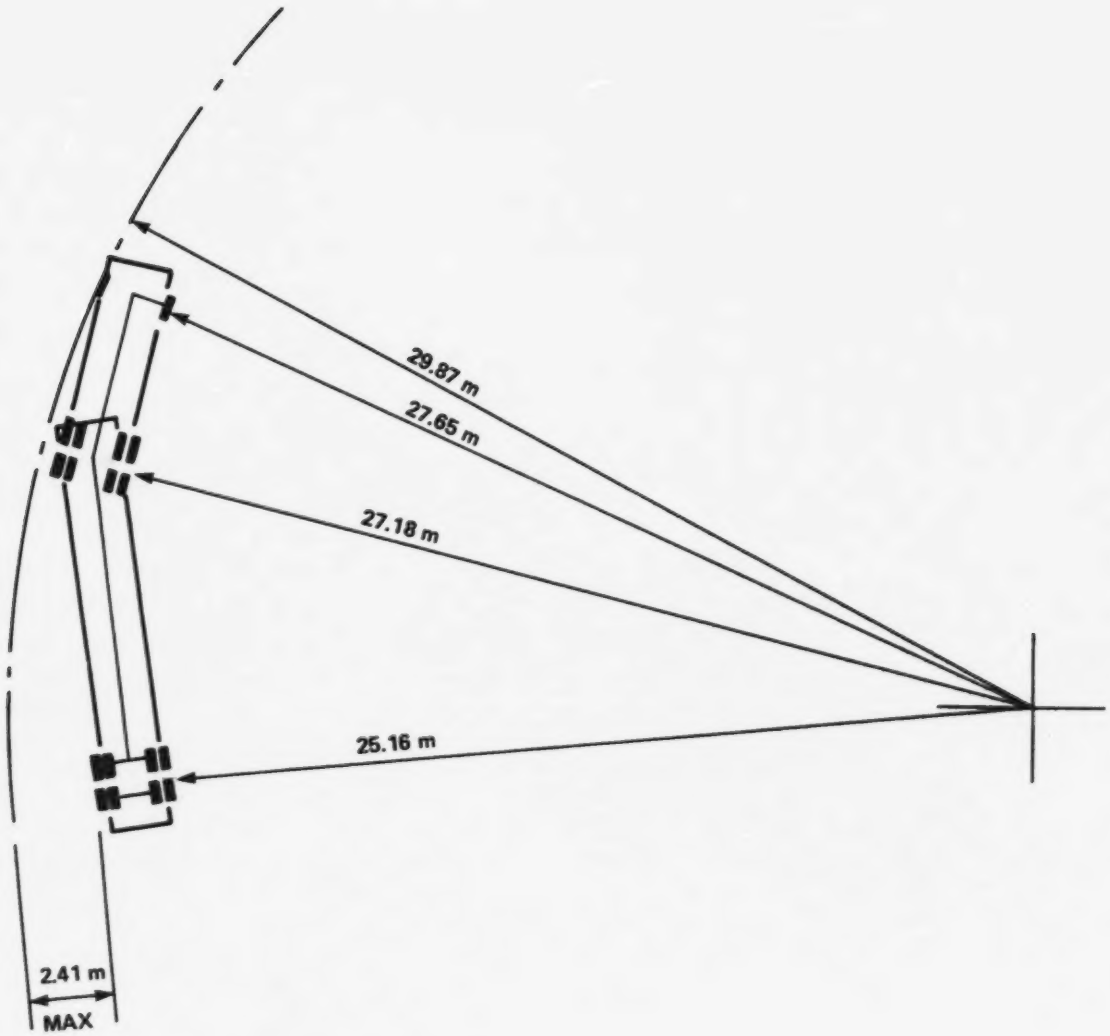
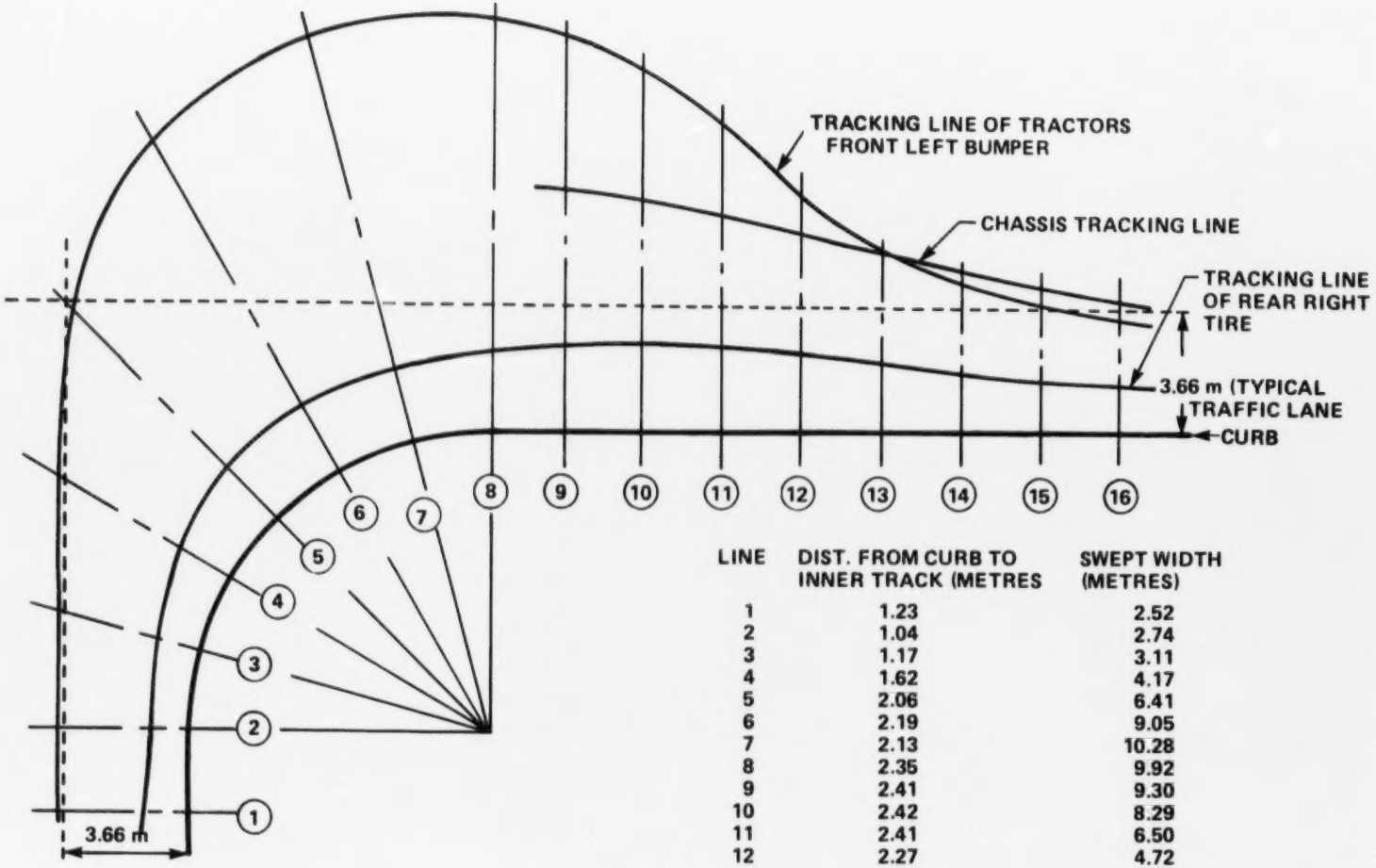


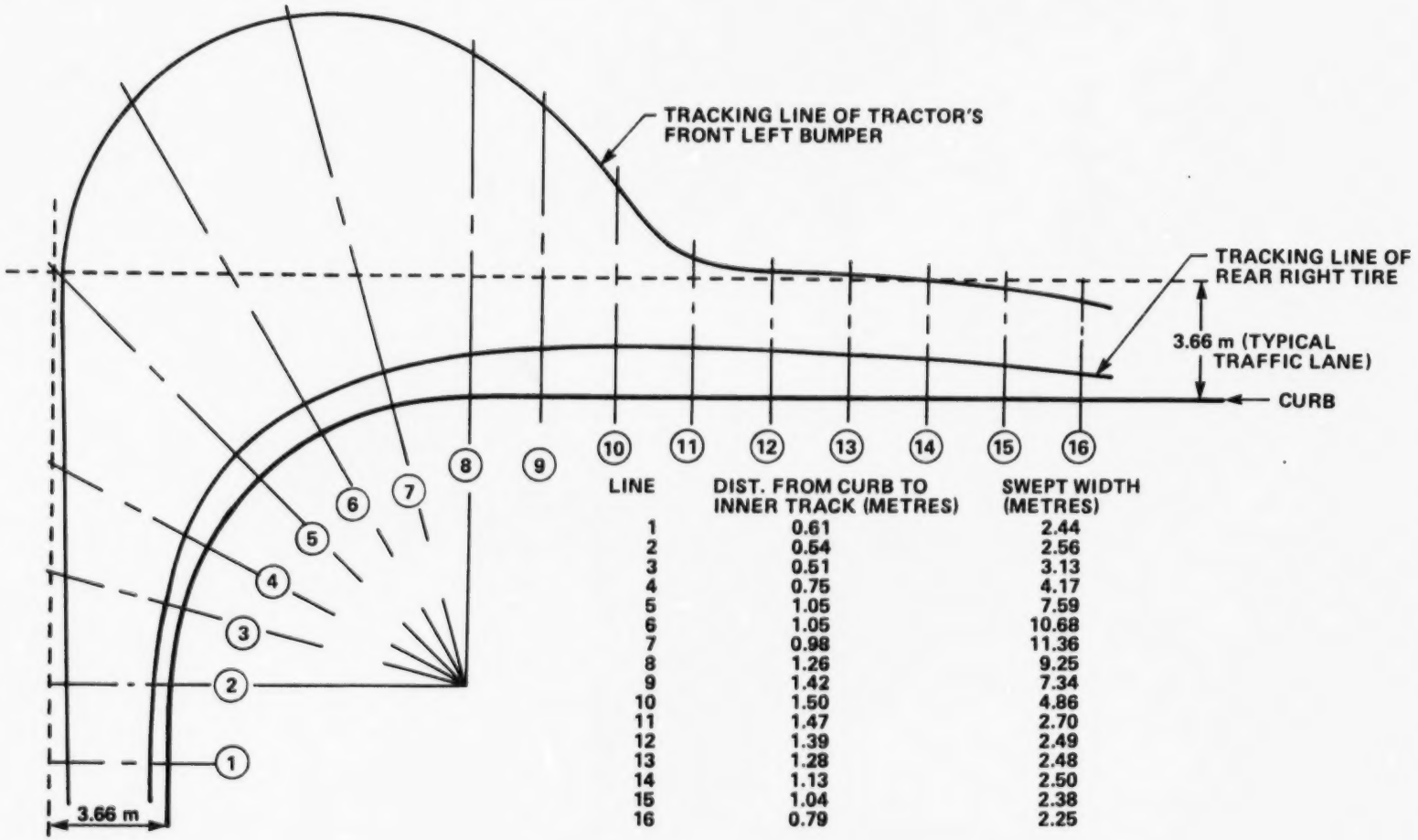
Figure 34/ Single 45 Trailer/MTC Tractor Steady State Offtracking Regime on 29.87 m Radius Pad

Figure 35/ Triple and Twin 45 on Constant Radius Offtracking Pad



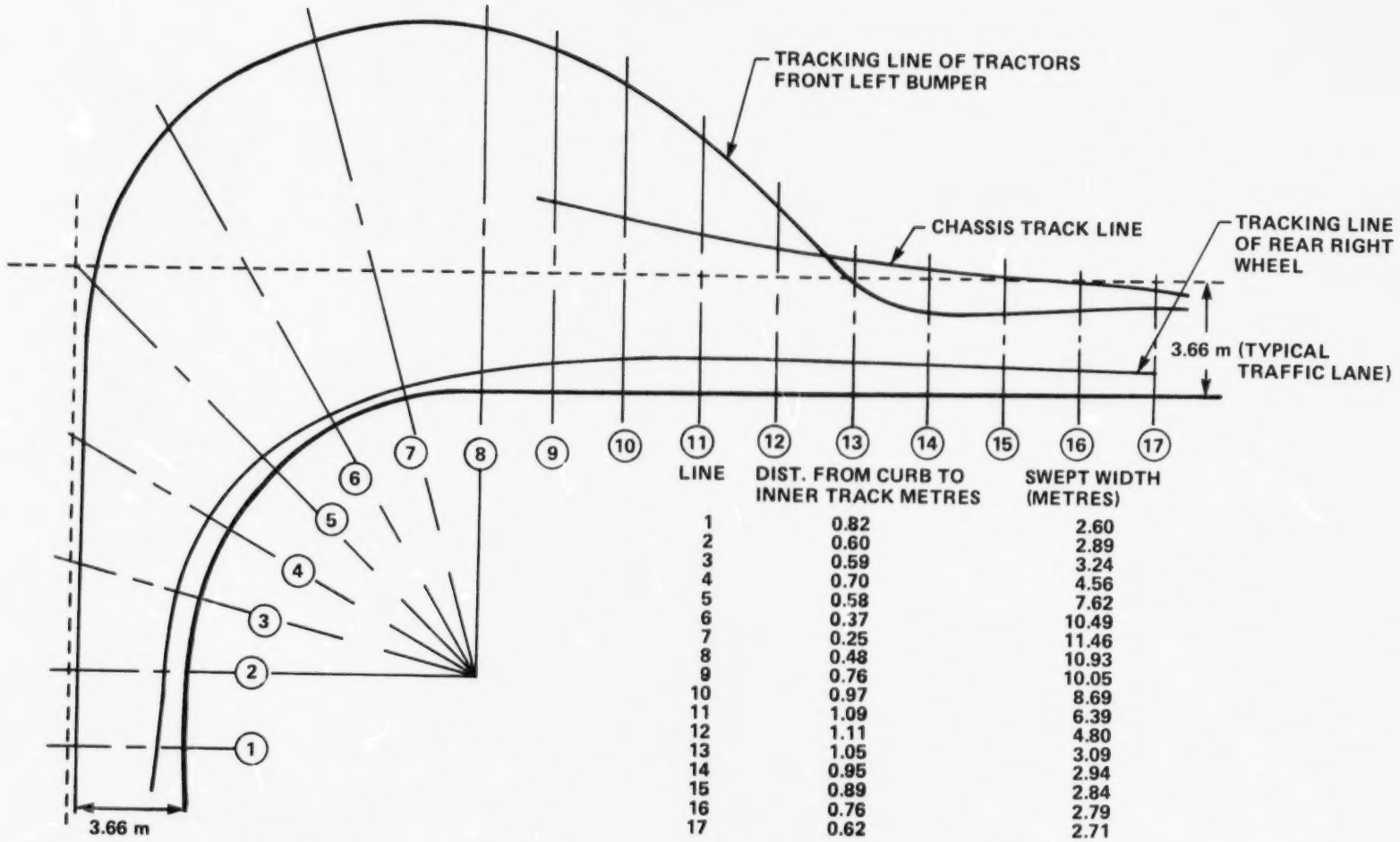
LINE	DIST. FROM CURB TO INNER TRACK (METRES	SWEPT WIDTH (METRES)
1	1.23	2.52
2	1.04	2.74
3	1.17	3.11
4	1.62	4.17
5	2.06	6.41
6	2.19	9.05
7	2.13	10.28
8	2.35	9.92
9	2.41	9.30
10	2.42	8.29
11	2.41	6.50
12	2.27	4.72
13	2.00	3.31
14	1.14	3.02
15	1.48	2.80
16	1.29	2.60

Figure 36/ Swept Path of Car Carrier Negotiating a Right Turn at a 9.144 m Curb Radius



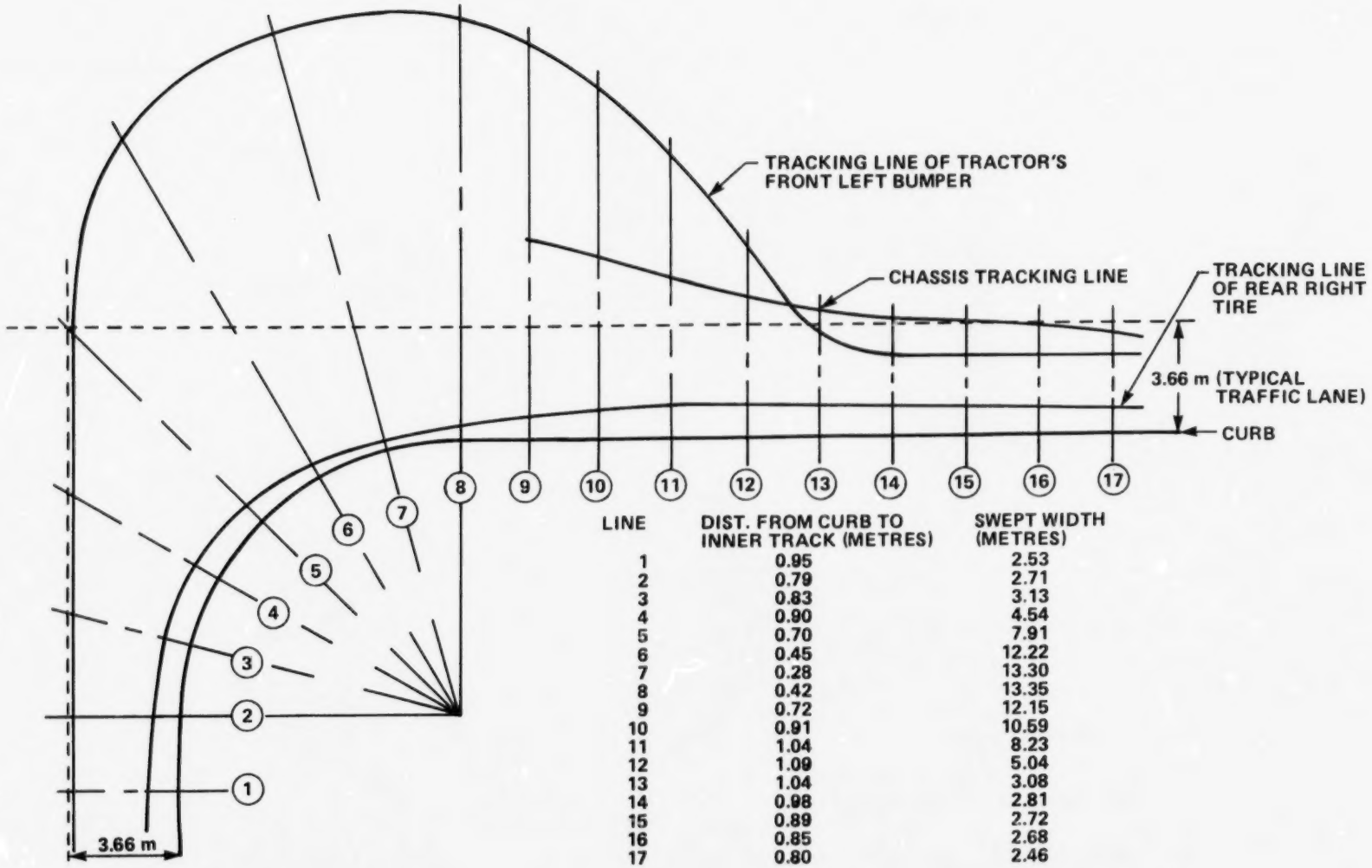
LINE	DIST. FROM CURB TO INNER TRACK (METRES)	SWEPT WIDTH (METRES)
1	0.61	2.44
2	0.54	2.56
3	0.51	3.13
4	0.75	4.17
5	1.05	7.59
6	1.05	10.68
7	0.98	11.36
8	1.26	9.25
9	1.42	7.34
10	1.50	4.86
11	1.47	2.70
12	1.39	2.49
13	1.28	2.48
14	1.13	2.50
15	1.04	2.38
16	0.79	2.25

Figure 37/ Swept Path of Triple Negotiating a Right Turn at a 9.144 m Curb Radius



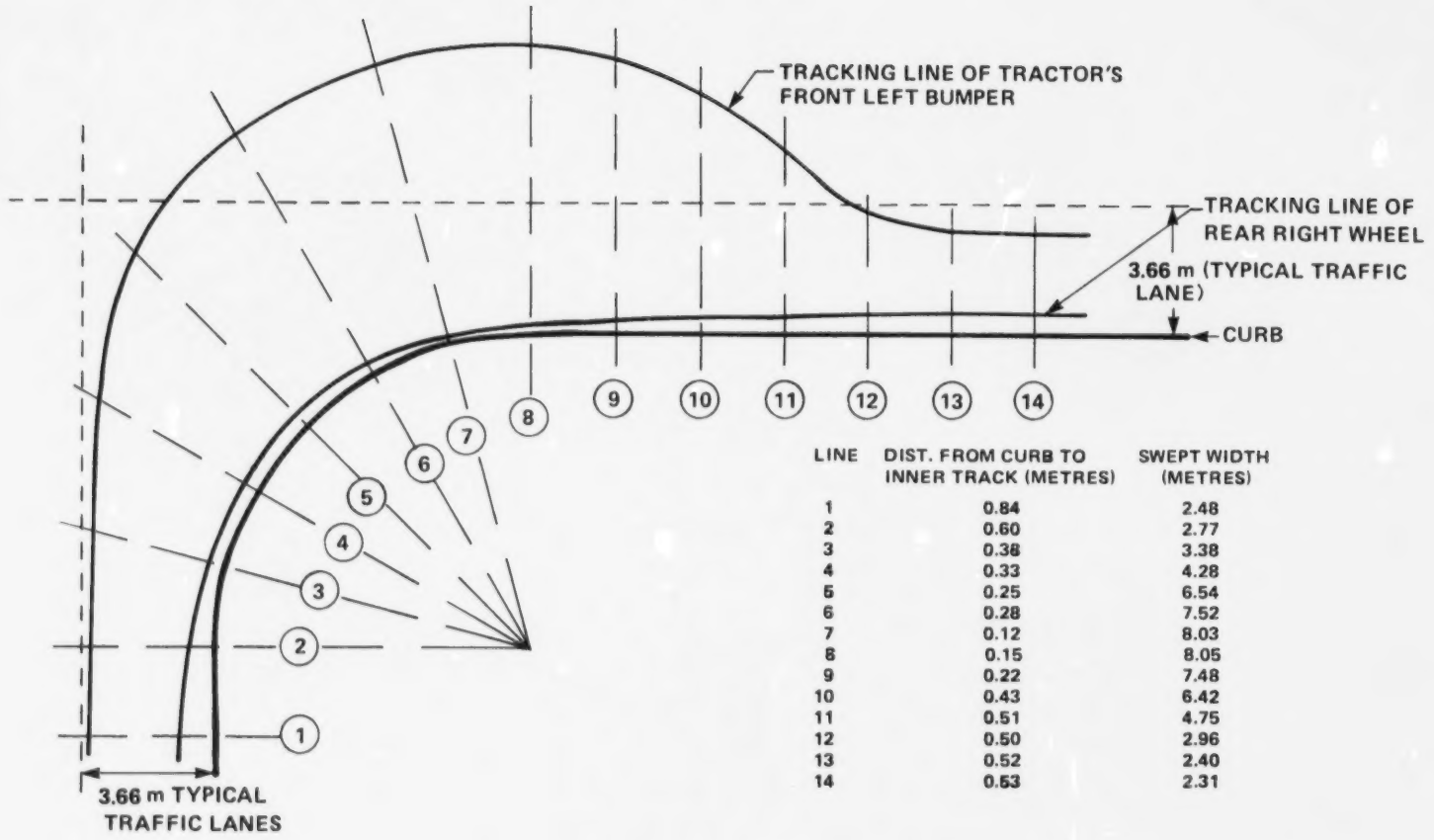
LINE	DIST. FROM CURB TO INNER TRACK METRES	SWEPT WIDTH (METRES)
1	0.82	2.60
2	0.60	2.89
3	0.59	3.24
4	0.70	4.56
5	0.58	7.62
6	0.37	10.49
7	0.25	11.46
8	0.48	10.93
9	0.76	10.05
10	0.97	8.69
11	1.09	6.39
12	1.11	4.80
13	1.05	3.09
14	0.95	2.94
15	0.89	2.84
16	0.76	2.79
17	0.62	2.71

Figure 38/ Swept Path of Twin (8.36 m Wheelbase) Negotiating a Right Turn at a 9.144 m Curb Radius


TRACKING LINE OF TRACTOR'S FRONT LEFT BUMPER
CHASSIS TRACKING LINE
TRACKING LINE OF REAR RIGHT TIRE
3.66 m (TYPICAL TRAFFIC LANE)
CURB
3.66 m

LINE	DIST. FROM CURB TO INNER TRACK (METRES)	SWEPT WIDTH (METRES)
1	0.95	2.53
2	0.79	2.71
3	0.83	3.13
4	0.90	4.54
5	0.70	7.91
6	0.45	12.22
7	0.28	13.30
8	0.42	13.35
9	0.72	12.15
10	0.91	10.59
11	1.04	8.23
12	1.09	5.04
13	1.04	3.08
14	0.98	2.81
15	0.89	2.72
16	0.85	2.68
17	0.80	2.46

Figure 39/ Swept Path of Twin 45 ft (9.5 m Wheelbase) Negotiating a Right Turn at a 9.144 m Curb Radius



LINE	DIST. FROM CURB TO INNER TRACK (METRES)	SWEPT WIDTH (METRES)
1	0.84	2.48
2	0.60	2.77
3	0.38	3.38
4	0.33	4.28
5	0.25	6.54
6	0.28	7.52
7	0.12	8.03
8	0.15	8.05
9	0.22	7.48
10	0.43	6.42
11	0.51	4.75
12	0.50	2.96
13	0.52	2.40
14	0.53	2.31

Figure 40/ Swept Path of MTC Vehicle and a Single 45 ft (13.72 m) Trailer Negotiating a Right Turn at a 9.144 m Curb Radius

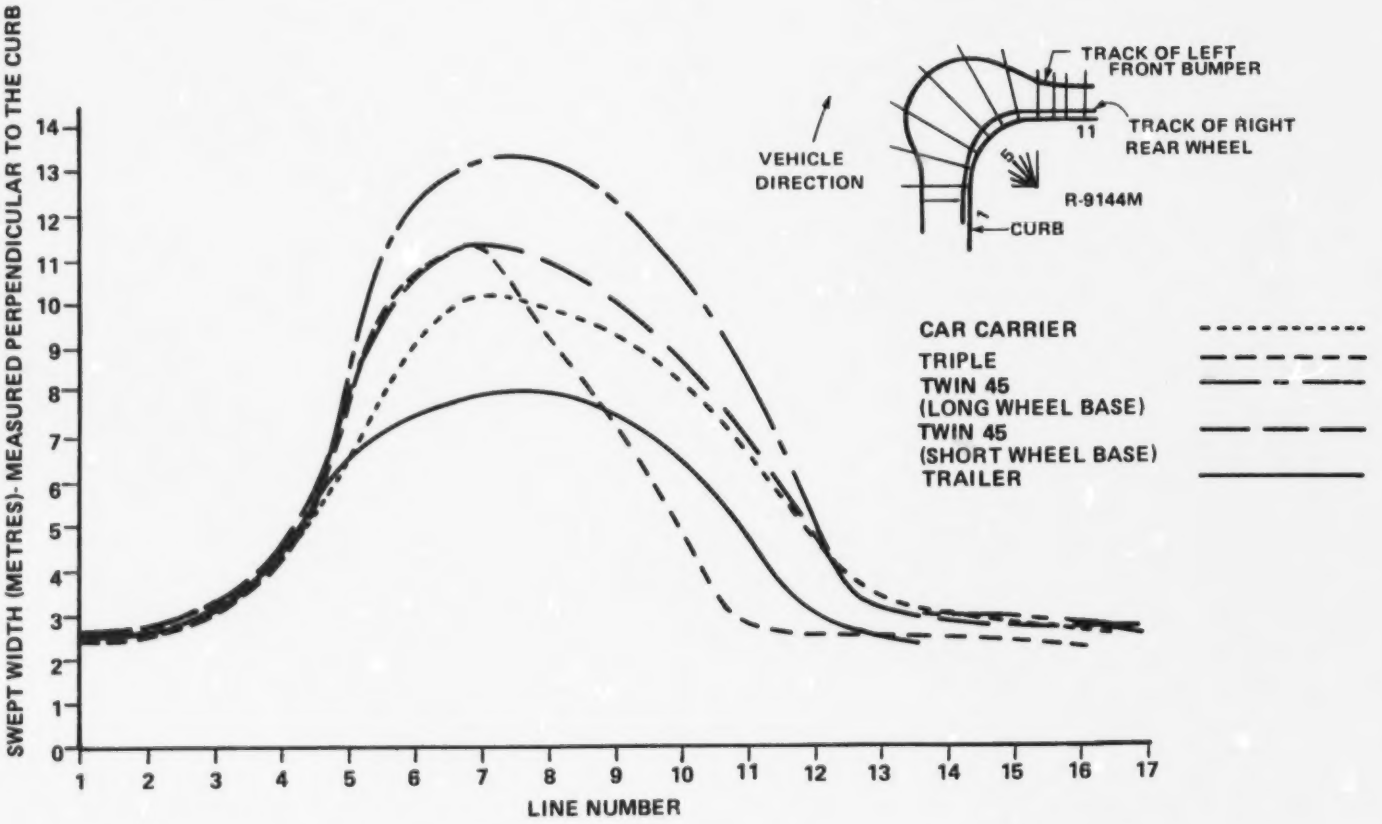


Figure 41/ Swept Path Width Plotted as a Function of Position for Five Truck Configurations

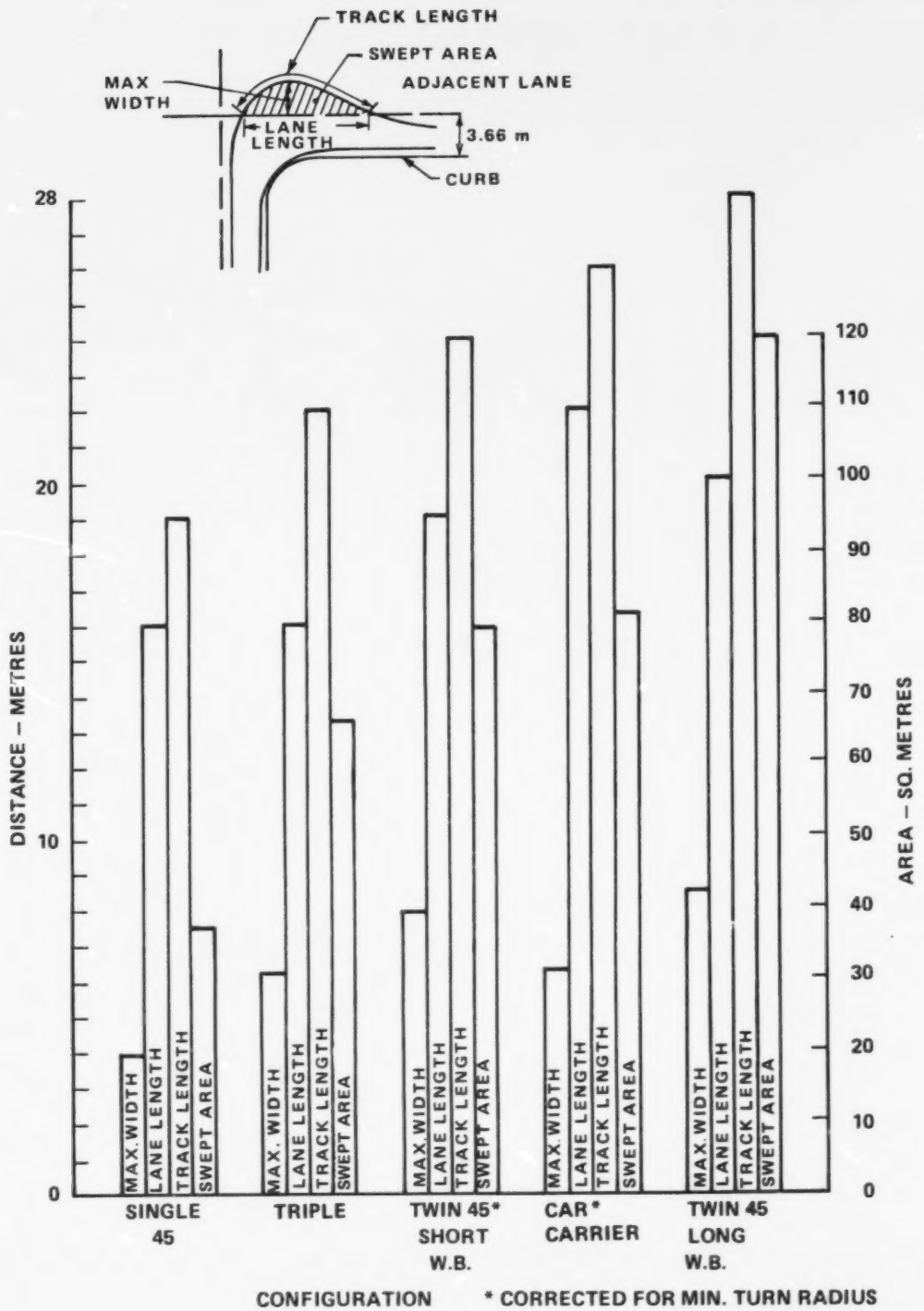


Figure 42/ Right Angled Turn Offtracking Out-of-Lane Durations

Figure 43a/ Swept Area Offtracking Course

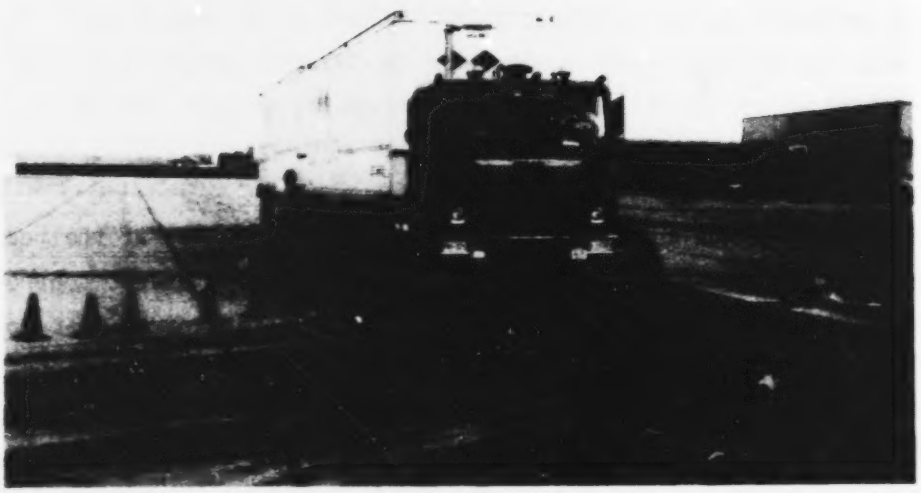


Figure 43b/ Twin 45 Shown Negotiating Swept Area Course

5/ DISCUSSION

5.1/ Lateral Acceleration and Response to Lane Change

Stability is not well defined in a truck context, due possibly to varying interpretations of the term stability, and the number of combinations of vehicular motion in which a train may become unstable.

Stability, in broad terms, is the property of a vehicle that allows complete directional control by the driver at all times. Technically it is the ability of a vehicle to return to an undisturbed state within a finite time after being subjected to an arbitrary temporary disturbance.

In the context of these tests, it was expected that stability would be governed by two basic modes, rollover or trailer swing, of the rear trailer in a combination.

It has been promoted that increasing the number of axles increases stability [1]. This may be true for straight line braking, but it is not generally true for lateral-directional motions, where the addition of trailers and dollies reduces stability [3]. A large group of interacting factors influence the stability of a vehicle train in a dynamic manoeuvre. Factors such as tire and suspension properties, which are nonlinear, spring lash, mixed tire types, load and its placement, and road surface friction have a significant effect on stability. It is likely that trucks in service have a wide variation in their stability characteristics due to normal ranges of configuration, component specification, operation and environment.

When a vehicle has a lateral acceleration amplification at the rear trailer less than 1.0, its response is still to some extent controlled by the driver. The qualification "to some extent" recognizes that rollover occurs from the rear trailer forward, with the rear trailer alone rolling at a somewhat lower lateral acceleration than that at which the whole vehicle rolls. However, the lateral acceleration at which rollover occurs is relatively uncomfortable, so the driver will usually try to keep it to a tolerable level, which thus controls trailer acceleration.

When the amplification is greater than 1.0, this slight control mechanism is absent.

The onset of instability demonstrated in these tests was associated with violent steering manoeuvres at high speeds. Such manoeuvres would only be necessary for accident avoidance in an emergency. Driver experience, and defensive driving techniques are the best means of avoiding such manoeuvres. Driver knowledge of the handling and stability characteristics of the vehicle, when loaded and empty, on wet and dry roads, is also necessary so the driver can select the appropriate strategy when an impending accident is apparent.

Low amplitude swaying of trailers is perceived as a concern by motorists, and may be related by them to imminent loss of control. The continuous small steer corrections necessary to follow the traffic lane tend to cause a wave action down through the vehicle, which may also be augmented by roadway undulations, and wind. Such motions are not indicative of instability, and are quickly quenched by inherent damping. Apparent sway in a train is perhaps enhanced by the ready perception of relative motion between van or tanker type trailers, as compared with the perception of relative motion between a semi-trailer and a much shorter tractor. This may give the impression of high amplitude swaying with the former, even though both have equal amplitudes. Excessive sway is certainly a prelude to trailer swing or roll instability, depending on the road surface, and will continue to amplify if influencing factors so allow. However, this requires the large and fast steer input typical of an emergency lane change manoeuvre, as used in this test, which is far in excess of the rather small steer corrections and slow lane change steer inputs used in normal driving.

5.2/ Brake Timing

The ideal way to bring a vehicle train to a stop, as outlined in Section 3.3.2, is progressive brake application from the rear forward. The MTC measurements revealed a reverse application sequence. It is believed that few, if any trains are operated with braking systems set up in this ideal fashion.

SAE recommended practice [4] specifies application and release times as the time taken for the air pressure at the axle to rise from 0 to 414 kPa (0 to 60 psi) and decay from 654 to 35 kPa, (95 to 5 psi) with 690 kPa (100 psi) supply. Timing standards apply only to new vehicle units, individual tractors or trailers. There are none for the whole vehicle. The Triple and Twin 45 tested were comprised of stock units, and although each unit was well serviced, lacked performance when evaluated collectively. The Car Carrier was designed as unit train and hence had shorter application times than the other two units.

The consequences of poor sequencing can create circumstances where under light and moderate short duration braking, the trailer brakes hardly engage. This creates a situation, in suitably adverse road conditions, where jackknifing of an empty or lightly loaded vehicle could occur. Excessive release times increase brake wear and lower overall fuel efficiency.

The hardware and installation techniques to improve brake system timing are currently available on the market. The test vehicle performance reflects a need for timing standards or guidelines. The owners of the vehicles showed a strong interest in understanding the performance of braking systems of trains, and the effects of braking system operation on stopping and stability.

5.3/ Stopping Distance

The Car Carrier was equipped with anti-lock brake modules, but did not appear to have the system active during the test. The Triple and Twin 45 were not equipped with anti-lock brake systems.

The unloaded vehicles all locked most of their wheels during this test which reduced the exercise to a measurement of tire/pavement adhesion. With locked wheels the stopping distance is a function of vehicle weight, initial speed, and the coefficient of kinetic friction. The heat generated at the brake drum was mimimal as a result of the near instantaneous wheel lock, so stopping distance did not decrease with the number of stops.

5.4/ Interaction with Traffic

The overlength vehicles operated on the highway in an unremarkable fashion. Occasions were noted when, as a result of slowing during grade climbing, traffic accelerated and overtook the trucks. The additional drawbar load on the overlength vehicles will reduce the tractors grade-ability and hence slow the tractor more than would a single semi-trailer, proportionally loaded.

Although a potential exists for offtracking on ramps, the vehicles appear to be at no disadvantage while performing lane changes on the highway.

The aerodynamic effect on surrounding traffic was observed to be similar to that created by tractor-trailers.

5.5/ Splash and Spray

Splash results when the impact of a tire on the pavement forces water out of the tire/pavement contact patch. These droplets are propelled away from the tire. Spray is formed when water droplets atomize upon impact with a smooth surface. Splash and spray occur only if there is water in the tires path, high velocity air around the vehicle, and turbulent air flow patterns around the wheels and through gaps in the truck configuration.

The splash and spray characteristics of the test vehicles during the demonstration were such that no distinction could be made between them and other tractor-trailer combinations operating on Highway 401 at the same time.

The comparison test at Centralia illustrated the point that anti-spray devices and trailer design do improve spray suppression, but do not entirely eliminate it. The aerodynamic nature of the trailer exterior walls appeared to influence the wake size, as did other factors. The spray comparison between the Car Carrier design with a low chassis and anti- spray devices against the higher van type trailers was clear, and spoke highly in favour of anti-spray devices.

A large vehicle operating on a highway during wet or rainy conditions causes splash and spray which affects the visual range of motorists.

Although the lateral spread of the splash and spray from the overlength trucks was similar to that of a conventional tractor trailer, the duration of spray for a passing motorist would be longer due to the increased vehicle length.

There appears to be a need for understanding of anti-splash/spray mechanisms, as it relates to entire vehicles for control of the summary effects, rather than control by component. Configuration peculiarities are such that characteristic spray patterns appear neither consistent nor similar for different trucks and hence require individual attention.

5.6/ Offtracking

Offtracking is the amount that a vehicle component deviates from the path of the steered member. All overlengths tested generated larger swept areas and higher offtracking than a tractor with a single 13.7 m (45 ft) trailer.

The magnitude of the offtracking of the overlength vehicles was such that access between major highways and terminals may be limited by intersection and roadway geometrics. The highway demonstration indicated that offtracking problems were not encountered on the access ramps used but distinctly left the impression that this was partially a result of driving technique and the characteristics of the ramps chosen.

During right angled, tight radius turns all vehicles including the tractor with single 13.7 m (45 ft) trailer entered adjacent traffic lanes to varying degrees. Although this is not a problem in itself, a turn will be slow, and long and wide sweeps into the adjacent lanes can interfere with other traffic, both vehicular and pedestrian.

6/ CONCLUSIONS

Three overlength trucks, a Triple, a Twin 45, and a double Car Carrier, were made available to the Ministry for limited testing. The vehicles were also demonstrated for the Ontario Commission on Truck Safety. The tests were conducted to gain insight into fundamental characteristics of such vehicles, and were not for the purpose of qualifying them for operation.

An aggressive emergency evasive manoeuvre demonstrated that lateral acceleration was amplified rearwards down the train, and might result either in rollover or trailer swing, depending upon vehicle characteristics, loading, and surface friction. An experienced driver who can anticipate the situation having accident potential, and who is fully aware of the stability and handling characteristics of his vehicle, appears essential for such overlength vehicles.

The brake timing of the two overlength vehicles made up from standard trailers was found less than ideal. The brake timing of the Car Carrier, which was presumably engineered as an entire vehicle, was more satisfactory. Components and techniques are available that can improve brake system timing on these longer vehicles.

When braked on a dry surface from 32 km/h, all test trucks locked the wheels and skidded to a stop.

All test trucks interfaced with Highway 401 traffic in a manner not inconsistent with routine behaviour and procedure.

All trucks generated a splash and spray similar to, although possibly somewhat longer in duration, than standard tractor-trailers. The Car Carrier, which was fully equipped with anti-spray devices, had a much reduced spray effect compared to those not so equipped.

All overlengths tested offtracked more than conventional tractor/single trailer combinations. True to life turn situations showed long durations and wide sweeps in adjacent lanes. Access to major highways may be limited at some locations by intersection geometrics.

ACKNOWLEDGEMENTS

This work was made possible by the owners of the trucks under test and demonstration. We thank Motor Carriers Ltd. of Oshawa, and Messrs D.N. Flett and W. Hayball, for the Double Car Carrier; International Carriers Ltd. of Oshawa, and Messrs R. Robertson and J. Rylance, for the Twin 45; and Intercity Truck Lines (Canada) Ltd., and Mr. R. Moore, for the Triple.

The tests were conducted at the MTC Test and Research Facility at Huron Park, Centralia. The assistance of Norm Carlton in vehicle preparation and driving the tests; of Bill Stephenson in instrumentation and data capture; of Cheuk Lam in engineering support, and other staff of MTC Research Laboratory, is gratefully acknowledged.

REFERENCES

[1] Western Highway Institute, "Motor Vehicle Size and Weight Standards, Western Regional Objectives," San Bruno, California, for the TRED Foundation, July 1980.

[2] Report of Ontario Parliamentary Select Committee on Highway Safety, September 1977.

[3] University of Michigan - College of Engineering/Highway Safety Research Institute, "Mechanics of Heavy Duty Truck Combinations," Notes for Course 8207, June 1982.

[4] SAE J982 Recommended Practice, 1982.